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DEVELOPING AN IDENTIFICATION AND TESTING SYSTEM FOR CARDIAC SURGICAL INSTRUMENT CAPABILITIES

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Abstract

This study developed an identification and testing system for cardiac surgical instrument capabilities for educational purposes, based on the concept of the Metaverse and the Roblox Studio Lua scripting language, through collaboration between a university and a regional hospital. The system supports simultaneous multi-user testing and evaluation of surgical instrument identification skills and can be used for education. It provides level-based challenge games where the players can determine whether their answers to questions are right or wrong, and which require more practice. The system allows paramedics in surgical care on 24-hour shifts to test themselves in different time periods and serves as a medium for testing that plays an important role in supporting the learning process and promoting the fun of learning.

Keywords: AI, Metaverse, Paramedics in surgical care, Roblox, Surgical instruments.

1. Introduction

A problem that urgently requires a solution in the medical field is that, although paramedics in surgical care in surgical care may find their jobs very demanding and busy, they still have to be familiar with, and make meticulous judgments regarding, surgical instruments [1]. Therefore, to improve the safety of patients in surgery and the quality of surgery, it is very important for them to accept sufficient education and training in advance [2].

2. Research Motives and Purposes

For most tests or exams, the minimum score for a participant to pass is 60 or 70. However, as any detail or decision in surgery may materially affect the patient's life, surgical care must be 100% safe, thus, a score of 60 or 70 is deemed insufficient [3]. In this sense, the purpose of this study is to make every paramedic score 100, and able them to deliver the correct instruments when providing emergency assistance in cardiac surgery, in order to cause no delays in surgery, facilitate the smooth performance of surgeries, enhance the tacit understanding between doctors and paramedics in surgical care, and improve efficiency during surgery [4].

While the Metaverse and AI (Artificial Intelligence) [5] have shown considerable potential in education and training, their application in medical education remains relatively rare. In view of the strong trend, and from the perspective of paramedic education, using Roblox to develop a simulation training system for testing surgical instrument capabilities when training paramedics in surgical care is a meaningful research direction [6].

In this context, this study aims to improve task performance in the operating room [7], as well as the capabilities of paramedics in surgical care in the operating room, to rapidly become familiar with surgical instruments and paramedics in surgical care learning performance [8]. In order to improve the task performance of paramedics in surgical care, training can be provided for paramedics in surgical care with high error rates during pretesting, which will facilitate good performance during further testing, thereby improving the overall performance of paramedics in surgical care and their task performance in the operating room [9].

3. Literature Review

The multi-sectional designs of virtual 3D healthcare learning environments have important effect on improving the usability and learning effects of 3D virtual healthcare learning systems [10]. The added-value applications of virtual worlds in healthcare education and skills training have further highlighted the importance of multi-sectional designs [11]. Integrating various interactive elements in these environments not only enhances engagement but also provides tailored educational experiences that cater to different learning styles [12]. The aforementioned findings constitute valuable references and can provide guidance when designing and implementing testing systems for surgical instrument capabilities.

3.1. Overview of traditional training methods and their effects and limitations

An inherent problem with efficiency in traditional reality-based training [13] is the diversity of surgical instruments, and it is impractical to conduct training with each instrument. Moreover, reality-based training requires many devices and

consumables, which have high costs [14]. Generally, traditional surgical training methods have many limitations, such as high costs, limited number of trainees, and the inability to realistically simulate surgical procedures, which hinders the development of critical skills necessary for effective surgical operations [15]. Moreover, assessment methods in traditional training are often subjective and prone to bias, which affects the reliability of evaluations [16]. This subjectivity may lead to inconsistencies in trainee assessments, ultimately impacting their preparedness for independent practice. Emerging technologies such as virtual reality and simulation-based training are being explored to address the limitations of traditional surgical training. Simulation training overcomes these limitations by providing a cost-effective, realistic, and impartial assessment method, improving residents' surgical skills in a safe environment [17].

During reality-based training, teachers experience extreme pressure regarding how they address problems. It has been pointed out that the challenges faced by teachers may affect their means of response, service capabilities, and workplace environments [18]. Therefore, in order to ensure the educational quality of the system and achieve effective operations, when developing a testing system for surgical instrument capabilities, it is necessary to consider how to avoid the negative impacts of teachers' pressure, while enhancing the learning abilities of trainees and improving the teaching environment [19].

Teachers' pressure is closely related to various factors, such as teacher-student relationships and teaching practices [20], thus, when designing a testing system for surgical instrument capabilities, the impact of teachers' pressure on education quality and students' achievements must be considered, including personalized interactive learning environments with corresponding support and added intervention measures to optimize teachers' performance and students' success rates [21].

The solution proposed in this study took advantage of AI and Metaverse technologies, as the applications of AI technologies in the medical field have already started refashioning traditional medical devices and services [22]. Moreover, the 3D virtual world of the Metaverse provides users with an immersive platform for learning and sharing patients' health conditions. Through VR (virtual reality) or AR (augmented reality) systems, AI plays an important role in many medical sub-fields [23]; for example, it helps improve diagnostic efficiency, makes medical decision-making more accurate and faster, provides better real-time medical imaging and radiology services, and facilitates more convenient simulated environments for the purpose of training interns and medical students, as well as offering opportunities to improve education quality [24].

Through AI and the Metaverse, this study was able to render the adopted training methods more efficient [25]; for example, training is available at all times for paramedics in surgical care in a three-shift system, which ensures that every test participant can repeat the training, meet higher standards, and prevent delivering the wrong instruments during surgery [26].

As shown in Fig. 1, different types of scalpels have slight differences in blade sizes (the three scalpels for thoracotomies have different blade sizes: 11#*1, 15#*1 and 20#*1) and blade shapes (curved, triangular and sharp). Scalpel designs have specific uses; for example, scalpel blades may be blunt or sharp, and vary in size, depth, and degree of curvature. However, scalpels are similarly packaged and can

only be identified by name, which is a possible factor that can make paramedics in surgical care deliver the wrong instrument or misplace the instruments.

Fig. 1. Comparison of different surgical scalpel types showing variations in blade size (11#, 15#, and 20#).

3.2. Implications of the innovative method with AI and metaverse

In the Metaverse, users can create, interact with, and experience virtual environments, as well as interact with other users [27]. The application of AI in the Metaverse can simplify content creation, making it easier for users to design their own virtual spaces [28]. AI is widely applied in various fields, and its usability (natural language processing, simulation-assisted machine learning, image recognition, etc.) is substantial [29]. AI-related research methods can be mainly divided into two approaches. One is to use virtual integration technologies, such as AR, VR, MR (mixed reality) and XR (extended reality) technologies. This approach appears to be a promising research direction in the development phase [30].

However, in fact, it takes 10 minutes or more for a single paramedic to check all required surgical instruments in reality or prepare them through AR, VR, or MR technologies. In such cases, if more than 100 paramedics in surgical care are involved, the total time would be more than 1,000 minutes. Considering the three-shift system for paramedics in surgical care and the limited number of blades for scalpel training, time is insufficient. Although purchasing multiple sets of AR, VR, or other wearable devices is a solution, there are clinical problems in actual operation, such as the risk for infection when they are in use [31]. The second approach is to use goggle-like devices, which are costly. Moreover, while board-like devices can be used, they are poorly produced and unable to deliver ideal 3D effects. Additionally, some devices can be used only with an attached smartphone, which are heavy in weight, and are similar to eye massagers, which can easily cause eye infections and are not suitable for people with eye diseases.

For training efficiency and ease of operation, the headset type is not practical, as it requires 30 minutes to one hour for a single person to practice one round, which will have high time costs to train everyone, and the devices must be repeatedly used in training, which is not as ideal as an AR-based or VR-based

method [32]. Therefore, this study proposed a more practical technology that allows operations with non-headset-type devices. This method adopts the concept of the Metaverse to directly present content in a virtual 3D space. By forming a learning framework that is compatible with the Metaverse [33], users can read questions merely by watching. This training method not only improves efficiency, but it also allows paramedics in surgical care to practice independently when there are no surgeries. Practice is important in the field of education [34], and this study regards it as one of the best training methods for paramedics in surgical care.

4. Research Methodology

The system in this study is designed to be developed alongside the PC version of Roblox (see Fig. 2), as Roblox can prevent infection risks and implement the required problem selection methods, while being suitable for Metaverse development and allowing direct multiplayer connections via mobile phones.

Roblox Studio was selected as the development platform due to its comprehensive feature set and educational suitability. The platform's integrated development environment provides built-in 3D modeling capabilities, allowing for accurate representation of surgical instruments with detailed texturing and lighting. The Lua programming language support enables implementation of custom training logic and assessment systems, while the built-in physics engine facilitates realistic object manipulation [35]. The platform's cross-platform compatibility ensures accessibility across different devices, making it ideal for healthcare facilities with varying technological infrastructure [36].

Additionally, Roblox Studio's networking capabilities support simultaneous multi-user training sessions, enabling group learning scenarios and instructor supervision [37]. The platform's automated data management systems facilitate progress tracking and performance analytics, essential for monitoring trainee development and ensuring achievement of the required 100% accuracy standard. User progress is tracked through a persistent data storage system, recording completion rates, accuracy scores, and time-to-completion metrics for each training module. The interface design prioritizes intuitive navigation, featuring clearly labelled instrument categories, search functionality, and filter options for different surgical specialties. To maintain educational quality, the system implements a progressive difficulty system where users must achieve a 100% accuracy rate in basic instrument recognition before advancing to more complex procedural scenarios. Real-time performance analytics are available to both trainers and trainees, with detailed breakdowns of common errors and improvement trajectories.

The photos of real surgical instruments were provided by a hospital to ensure that the scenarios with instruments in the system are realistic, and surgical instruments can be prepared based on supplies in the most comprehensive and reliable manner to ensure the smooth performance of surgeries.

Furthermore, the system was developed using the Lua scripting language, which provides audio capabilities in both English and Chinese to facilitate recognition of the correct names of surgical instruments [38]. Moreover, once a correct answer is made to a question, it may be unnecessary to answer other identical questions, thus, question selection is conducted in a randomized manner.

When a participant fails to answer all questions correctly, the questions will be randomly re-selected to prevent any question from appearing again.

The training system implements three progressive module levels, each designed to build comprehensive surgical instrument competency. The Basic Module covers fundamental cardiac surgical instruments including various scalpels (11#, 15#, 20# blades), forceps (DeBakey, tissue, and Adson types), retractors (Finochietto, Weitlaner), and specialized cardiac instruments (coronary probes, vessel loops, cardiovascular clamps). The Intermediate Module focuses on instrument sets for specific cardiac procedures, teaching proper organization and sequencing of Mayo scissors, Metzenbaum scissors, needle holders, and specialized instruments like aortic punches and internal mammary artery retractors. The Advanced Module simulates emergency scenarios requiring rapid instrument identification and preparation, incorporating time-pressure elements while maintaining accuracy requirements.

Performance evaluation utilizes multi-dimensional metrics to ensure comprehensive assessment. The primary metrics include：

1. Identification Accuracy: Measured as a percentage of correct instrument identifications, with a mandatory requirement of 100% accuracy overall.
2. Response Time: Tracked in seconds for each identification challenge, with timing beginning immediately when the problem-solving starts.
3. Sequence Accuracy: Evaluation of correct instrument preparation order for specific procedures.
4. Error Pattern Analysis: Tracking of common misidentifications to inform targeted training for different scenarios.
5. Consistency Metrics: Monitoring performance stability across multiple challenge levels.

The system automatically logs these metrics in a database, generating individual performance profiles that track all progress. Detailed backend analytics can display both individual and group performance trends, enabling targeted instruction where needed. This data-driven approach ensures that medical staff not only achieve the required 100% accuracy but maintain this standard consistently under various conditions and time pressures.

The main testing function of the system is to allow users to select answers in either English or Chinese based on the presented photos. Users can operate the system independently in either English or Chinese, freely choosing photos and options, and selecting the type and size of answers according to the test. Answer options can be in English or Chinese, and there are four modes for photos: 'View photo and choose answer (Chinese or English)', 'Read English text and choose corresponding photo', 'Read Chinese text and choose corresponding photo'. The Metaverse space in Roblox can be highly customized. While the surgical instrument images provided by the hospital remain unchanged, subsequent scene modeling and question text variations can use AI for personalized enhanced training based on results. The final score is evaluated by the system, thus addressing potential biases and limitations in traditional training. Specifically, the system allows four scenarios:

- Choose the corresponding English answer based on the random photos.

- Choose the corresponding Chinese answer based on the random photos.
- Choose the corresponding answer in photo based on the random English text.
- Choose the corresponding answer in photo based on the random Chinese text.

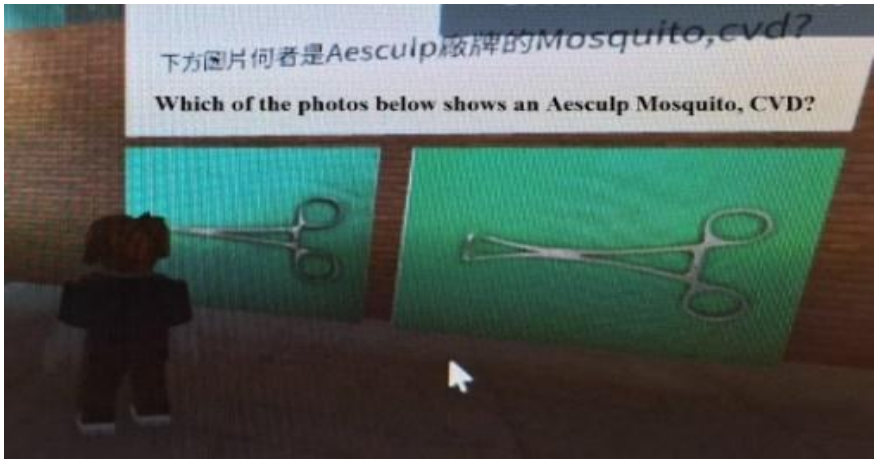

Fig. 2. Actual problem-solving screenshots of user scenarios in Roblox.

5. Results Analysis

This study aims to develop a system that meets the requirements for reducing error risks. Therefore, there is no need to worry if the provided photos are not perfectly clear. For example, Fig. 3 shows a simulated character entering the hospital, Fig. 4 shows the character answering questions, and Fig. 5 shows the character progressing to the next level after passing the current one. These photos were also used for demonstration tests, which were participated in by several emergency responders from surgical nursing.

Fig. 3. Hospital modelling simulation using PC version of Roblox studio.

It is important to note that this testing was based on preliminary internal trials conducted within the hospital. The research team collaborated closely with the head of the hospital's nursing department to ensure the system's alignment with actual medical practices and training needs. To respect the privacy of hospital staff, as mandated by hospital regulations, the system testing was not expanded beyond this initial group. This approach maintains ethical standards while still providing valuable insights into the system's performance and potential.

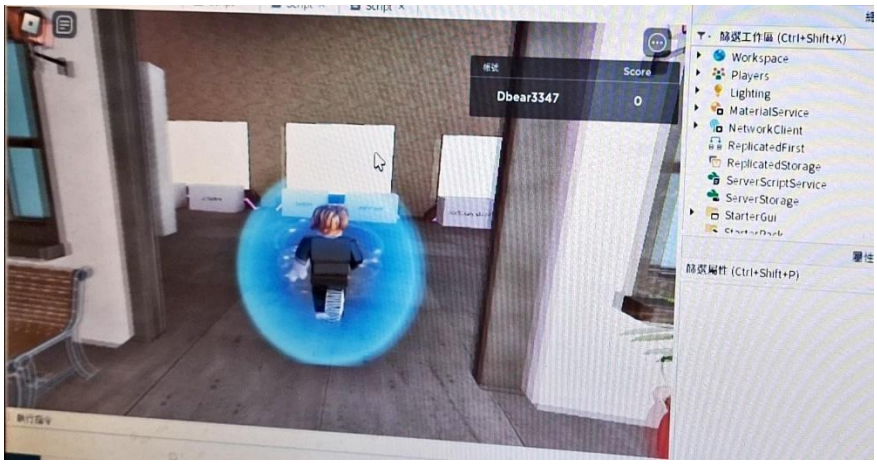

Fig. 4. Entering the hospital.

Fig. 5. Screenshot of the character answering questions.

In this innovative virtual training system, participants engage in a gamified learning experience designed to simulate real-world medical scenarios within a Metaverse environment. The system incorporates elements of game design to enhance engagement and reinforce learning outcomes. When the character first enters the hospital, the test participant's score is 0 points. After correctly answering all questions in the first Metaverse room, the score becomes 30 points (see Fig. 5)

After completing the first room, the character proceeds to the next Metaverse room, indicating progression to a new set of challenges or a different medical scenario. As illustrated in Fig. 6, if any question is answered incorrectly, the character will disintegrate and have to restart the challenge as shown in Fig. 7. The system's strict accuracy requirements align with actual operating room protocols, where mistakes in instrument identification can have serious consequences. This design choice reflects the high standards of surgical care while maintaining an engaging learning environment.

Fig. 6. Screenshot of the character entering the next level after passing the current level.

Fig. 7. The character will disassemble if any question is answered incorrectly.

Then, the score of the test participant reached 40 (see Fig. 8) before the character moved to the next location, where he scored 60 (see Fig. 9). If the score increases cumulatively, it means that a test participant has answered a group of questions correctly. Although the medical field requires a high level of accuracy, a test participant can still be recognized as making progress in judging surgical

instruments if their score increases from the pretest to the after-test. In this test, the fact that he made progress was recognized by hospital supervisors.

Fig. 8. The test participant scored 40 when answering questions.

Fig. 9. The test participant continued to answer questions and scored 60.

6. Conclusion

Through AI and Metaverse technologies, more personalized learning experiences are provided, and learners can perform practical operations and engage in simulations in virtual environments, which can improve their learning performance. Meanwhile, the real-time monitoring and feedback enabled by AI technology can help learners receive assessment results and guidance in real-time, as well as improve their skills and decision-making abilities. In terms of results analyses and the impact of the system on medical talent training, this innovative method facilitates rapid analysis of training results with higher accuracy and provides a greater understanding of trainees' performance and needs. In addition, this method is conducive to adjusting training content and methods in a targeted manner to improve the training effects and abilities of medical talents.

Compared with traditional reality-based exercises and in-class training, this innovative method may be more flexible and interactive and provide a richer learning experience and higher training efficiency. By comparison, the advantages and potential of AI and the Metaverse in improving medical talent training can be realized.

In conclusion, the integration with hospital management needs to be highlighted, especially the impact of this system on improving the accuracy of hospital employees in training. The application of the model proposed in this study in multiple hospitals, especially in the operating room, can improve the accuracy of surgical care.

Moreover, this model is also applicable to factories by providing procedural care assistance that is more accurate. This model can be duplicated in different factories, which can help improve familiarity with behavioural patterns when a foreign language is used. This model is also critical to ordering procedures, as it can help prevent ordering a wrong type, thus, ensuring that large down payments do not need to be refunded.

In summary, this model is expected to provide effective and accurate managerial benefits in different fields, especially in the medical field and industrial sector.

Considering cost, infrastructure requirements, and institutional feasibility, the Roblox-based system primarily involves code construction, requiring only a smartphone or computer for personnel to use, thus making it cost-effective. Furthermore, feasibility is a key factor; systems with user-friendly interfaces and minimal hardware requirements are often more easily adopted in diverse medical settings. However, disparities in resource availability may hinder implementation, especially in rural or underfunded areas. Additionally, the need for ongoing support and maintenance may lead to budget constraints, particularly for institutions with limited financial flexibility. Therefore, a customized approach that considers each medical institution's unique circumstances is crucial for successful implementation. Overall, while this system shows promise, careful planning and resource allocation are essential for its widespread adoption.

7. Suggestions

This study developed an identification and testing system for surgical instrument capabilities, and applied AI and Metaverse technologies to improve medical education and training. By integrating AI and Metaverse technologies, a more personalized and interactive learning environment can be provided to help paramedics in surgical care improve their skills and decision-making abilities. This innovative method can improve training effects and promote knowledge exchanges between global practitioners in the medical industry.

In terms of future research, in order to continuously promote the innovation and development of paramedic training, it is suggested that further exploration can be conducted in other research directions, such as personalized learning models, data analysis and predictions, VR technologies, and cross-border cooperation and team training. In the future, this can be further validated through larger-scale trials or real-world implementation.

It is also suggested that a Metaverse-based platform for cross-border cooperation can be established to promote knowledge sharing and professional

exchange, as well as to continuously improve this system and adopt other training methods for the purpose of improving training effects. Additionally, it is also of the utmost importance to safeguard learners' privacy and data security. With these measures, we can advance better applications of AI and Metaverse technologies and promote the innovation and development of paramedic training.

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