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A Low-Cost and High-Efficiency Virtual Simulation Training Model for Crime Scene Investigation

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ABSTRACT This paper proposes a low-cost and high-efficiency training model for crime scene investigation (CSI) based on virtual reality (VR) technology. Traditional CSI teaching faces challenges such as high costs and limited effectiveness. VR technology, capable of simulating realistic scenarios, provides an immersive and interactive learning experience. This study explores the use of free and open-source software and platforms to create virtual investigation scenarios and employs a collaborative development model involving teachers and students to enhance resource quality and development efficiency. While the proposed model offers advantages such as low cost, high efficiency, and enhanced safety, it also faces challenges, including technical barriers, hardware limitations, and software functionality constraints. The paper concludes by proposing solutions to these challenges and discusses the application prospects of VR technology in CSI training.

KEY WORDS Virtual Reality; Crime Scene Investigation; Training Model; Low Cost; High Efficiency

1. INTRODUCTION

The crime scene investigation (CSI) training course is a core requirement for majors such as criminal investigation and forensic science at many public security and law enforcement academies. However, current CSI training courses often adhere to traditional teaching methods, which face significant limitations. These include constraints imposed by time and space, difficulties in fully replicating case scenarios, and limited opportunities for students to independently investigate cases, all of which hinder the overall effectiveness of the teaching process. ^[1]

Although multimedia tools, such as slideshow presentations, real-life crime scene setups, and short video recordings, are occasionally utilized to provide an immersive learning experience, their impact remains limited. Students often struggle to grasp the overall structure of a crime scene, and the knowledge acquired tends to be fragmented and lacks systemic coherence.

Integrating virtual reality (VR) technology into CSI training presents a potential solution to these issues. VR not only consolidates traditional methods of scene documentation but also enables a realistic, intuitive, and comprehensive reconstruction of crime scenes. Interactive techniques allow for detailed examination of evidence within the scene, and animations can dynamically simulate criminal activities,

offering unparalleled visualization of the investigative process compared to traditional static recording methods.

However, widespread adoption of this approach is hindered by high costs and a steep technical learning curve, both of which require significant time and resources to overcome. Consequently, the application of VR in CSI training remains in its preliminary stages of development and exploration. A critical research focus is, therefore, to reduce costs and enable rapid adoption of this technology.

To address these challenges, the author utilized resources from the institution's Evidence Science Laboratory and conducted a series of experiments with general-purpose 3D software. This research gradually established an implementation workflow for VR technology in CSI training, and the findings are shared here to encourage further discussion and collaboration among peers.

2. OVERVIEW OF VIRTUAL SIMULATION TRAINING FOR CRIME SCENE INVESTIGATION

Virtual simulation training for crime scene investigation (CSI) is a teaching approach that leverages virtual reality (VR) technology, computer simulation, and other auxiliary tools to replicate real-world CSI environments and processes for professional training purposes.

This teaching method is characterized by the following

features:

2.1. Immersion

Through VR technology, students experience an immersive environment, as if they were physically present at an actual crime scene. This immersion is achieved through multi-sensory simulation, including visual, auditory, and even tactile feedback, allowing students to comprehensively perceive the virtual scenario and experience every detail of the investigation process. In such an environment, students can fully focus on their studies, naturally interact with the surroundings, and deepen their understanding of theoretical knowledge while mastering practical skills.

2.2. Interactivity

Students can interact with objects in the virtual environment, such as moving items or using investigative tools. This interactivity goes beyond basic clicking and dragging to include complex operations and real-time feedback, such as adjusting equipment, executing procedures, or analyzing data. Using various input devices—keyboards, mice, VR controllers, etc.—students can manipulate elements within the virtual environment. The system responds dynamically to their actions, such as altering the scene state, providing informational prompts, or initiating specific tasks. This real-time interaction greatly enhances student engagement and active learning, allowing them to learn through practice and grow through exploration, leading to a deeper understanding and mastery of knowledge and skills.

2.3. Repeatability

The virtual simulation environment can be reused indefinitely, enabling students to “transcend time and space constraints” and practice repeatedly. This allows them to understand the entire process and multiple dimensions of crime scene investigation, ensuring they grasp the necessary knowledge and skills comprehensively. [2] Through repeated practice, students can gradually correct errors and deepen their understanding of procedural workflows until they achieve proficiency. Repeatability also enables instructors to flexibly adjust teaching pace and difficulty based on student progress, ensuring every student can advance at their own pace. This characteristic not only improves learning efficiency but also enhances the flexibility and personalization of the learning process.

2.4. Safety

Training in a virtual environment eliminates the safety risks associated with real-world crime scenes. By utilizing VR technology, students can operate in a fully controlled virtual space, avoiding potential injuries and equipment damage that may occur during real-world practices. This level of safety allows students to experiment and explore freely without psychological pressure, fostering a thorough understanding of procedures and principles. Meanwhile, instructors can design various extreme and malfunction scenarios, such as simulating complex cases like large-scale

explosions or fires, in addition to simpler cases like murder or theft. [3] This enables students to learn response strategies without any risk, enhancing their safety awareness and emergency handling capabilities in real-world applications.

Teaching Objectives

The primary objective of virtual simulation training for CSI is to cultivate students' comprehensive mastery of theoretical knowledge and practical skills related to crime scene investigations. Specific goals include: Enhancing students' operational skills in crime scene investigation, enabling them to proficiently use various tools and techniques; Strengthening their understanding of investigation processes and critical steps, thereby improving their analytical and problem-solving abilities; Simulating realistic scenarios to develop students' emergency response and decision-making skills; Fostering teamwork and communication skills to prepare students for future roles in related fields.

Teaching Content and Methods

The content of virtual simulation training for CSI includes fundamental theories, operational procedures, technical standards, and case analysis. It combines VR technology with traditional teaching methods to achieve optimal learning outcomes.

Theory Instruction: Basic theories and legal frameworks of CSI are taught through lectures to ensure students acquire a solid knowledge base.

Practical Demonstrations: Virtual simulation platforms are used to demonstrate and practice operational procedures, enabling students to learn how to handle investigative tools, measure scenes, collect evidence, and document findings in a safe virtual environment.

Case Analysis: Typical CSI cases are analyzed to enhance problem-solving skills.

Interactive Methods: Role-playing and group collaboration are widely employed to enrich students' practical experience and teamwork capabilities.

Report Writing and Presentation: Simulated report preparation and oral presentations are conducted to improve students' communication and expression skills, ensuring a seamless integration of theory and practice.

By combining advanced technology with diverse teaching strategies, this approach provides a robust foundation for cultivating the next generation of professionals in crime scene investigation.

3. IMPLEMENTATION APPROACH FOR LOW-COST AND HIGH-EFFICIENCY VIRTUAL SIMULATION TRAINING IN CRIME SCENE INVESTIGATION

3.1. Low-Cost Development Environment

The development of virtual simulation teaching resources for crime scene investigation does not necessarily require high costs. Based on the author's personal experience, a

computer platform costing less than 10,000 RMB is sufficient to meet the resource development needs. Regarding hardware configuration, the author used relatively standard equipment: a laptop computer running the Windows 11 operating system. The laptop is equipped with an Nvidia RTX 2060 graphics card with 4GB of video memory. This graphics card performs excellently when handling graphically intensive tasks and runs virtual simulation software smoothly. Additionally, the laptop has 16GB of memory, ensuring smooth performance during multitasking. Its 500GB hard drive, while not particularly large, is adequate for storing teaching resources and related data.

In terms of software selection, the author prioritized practicality and cost-effectiveness and thus chose several free and open-source software tools for developing teaching resources:

SweetHome3D: A software tool that enables the rapid creation of interior 3D models, making it highly suitable for constructing virtual investigation scenarios.

Blender: A powerful 3D modeling, animation, and rendering software with open-source features that allow educational users to freely use and modify it, making it ideal for creating complex investigation scenes and animation effects.

SketchUp 8: Known for its user-friendly interface and rapid modeling capabilities, it became another essential tool for the development of teaching resources.

To share the completed virtual investigation scenes with students, the author chose Sketchfab, a free platform. Sketchfab supports online presentation and interactive 3D content, allowing students to access and manipulate virtual scenes directly via a web browser on any device without the need to download any additional software. This greatly simplified the process of distributing and using teaching resources.

3.2. Convenient and Efficient Development Process

During the development of virtual simulation teaching resources for crime scene investigation, a collaborative model involving both teachers and students was adopted. This model not only improved the quality of resources but also enhanced the sense of participation and belonging among both teachers and students.

The entire development process started with the most basic step: *collecting and organizing case materials*. This step involved the joint participation of teachers and students, who gathered a series of representative and educationally valuable crime scene investigation cases through various methods such as literature reviews, field surveys, and internet searches.

Next was the *drawing of site floor plans*. In this stage, students learned how to convert real-world crime scenes into floor plans, a skill critical for understanding site layouts and spatial relationships. The drawing of these floor plans

required precision and also needed to account for the requirements of subsequent 3D modeling. Therefore, every detail had to be carefully considered.

Following this, the team used software tools such as *SketchUp 8*, *SweetHome3D*, and *Blender* to create 3D models of the sites. Each software tool had its unique strengths:

SketchUp 8: Its rapid modeling capabilities allowed beginners to quickly become proficient.

SweetHome3D: It provided a wealth of interior design elements, making it convenient to construct realistic indoor scenes.

Blender: With its powerful features, it was well-suited for creating more complex and refined models.

During this process, students not only learned 3D modeling techniques but also gained a deeper understanding of various aspects of crime scene investigation.

Once the modeling was complete, the next step was to *upload the models to Sketchfab* for interactive design and display. By leveraging Sketchfab, the teaching resources were transformed from static to interactive formats. Students could directly manipulate the models on the platform and observe the scenes from different perspectives. This immersive learning experience significantly improved the teaching effect.

Efficient Development Timeline

The entire development process, from case collection to final display on Sketchfab, took less than a week. This highly efficient workflow minimized time costs while significantly enhancing the efficiency of resource construction. It allowed for a rapid response to teaching needs, enabling timely updates and enrichment of teaching resources. This, in turn, continuously improved the quality of virtual simulation training for crime scene investigation.

4. ADVANTAGES AND CHALLENGES OF LOW-COST AND HIGH-EFFICIENCY VIRTUAL SIMULATION TRAINING FOR CRIME SCENE INVESTIGATION

4.1. Advantages

From the perspective of course implementation, this low-cost and high-efficiency virtual simulation training model for crime scene investigation demonstrates significant advantages.

First, this model excels in *cost control*. Traditional training methods often require substantial financial investment to purchase and maintain expensive laboratory equipment and consumable materials. In contrast, this virtual simulation training approach eliminates reliance on hardware by using software simulation, significantly reducing the initial investment and daily operational costs. This enables institutions to provide high-quality practical teaching within limited budgets.

Second, the application of virtual simulation technology introduces *unprecedented diversity* to crime scene

investigation training. This technology can precisely simulate a wide range of complex and variable on-site environments, covering all aspects of crime scene investigation, from simple evidence collection to complex crime scene reconstruction. Such training scenarios are not only diverse but can also be customized to meet specific teaching needs, allowing students to enhance their practical skills and ability to handle emergencies in various virtual scenarios. This prepares them to perform more confidently and competently in real-world situations.

Moreover, this training model overcomes the *time and space limitations* of traditional methods. Conventional training courses often require students to be present in designated laboratories at specific times, whereas virtual simulation training allows students to access the system from anywhere using personal computers, tablets, or smartphones. This flexibility is particularly beneficial for part-time and distance education students, greatly enhancing the convenience of learning. Furthermore, it enables students to arrange their study time and pace according to their individual learning needs and interests, ensuring better mastery of crime scene investigation knowledge and skills.

4.2. Challenges

However, the promotion and application of this low-cost and high-efficiency training model also face several challenges that cannot be ignored.

First, technical barriers are a primary concern. The application of virtual reality technology requires both teachers and students to have a certain level of technical knowledge, including operational skills with virtual simulation software and an understanding of VR principles. For teachers and students with weaker technical backgrounds, this poses a significant challenge. Addressing this issue may require additional resources and time for specialized training to improve the technical proficiency of relevant educators and learners.

Second, hardware limitations present another significant challenge. Virtual simulation software often demands high computer specifications, including powerful processors, high-performance graphics cards, and sufficient memory. However, some students may lack access to the required hardware due to financial constraints or other reasons, preventing them from effectively participating in training outside the classroom or school facilities. This limits the widespread adoption of virtual simulation training.

Third, software functionality limitations can also be problematic. While free or low-cost virtual simulation software can meet some teaching needs, they may lack features necessary for professional teaching, such as detailed simulation, data processing, and user interaction capabilities. These limitations can affect the quality and effectiveness of training. Addressing this issue may require the development of customized teaching software or the adoption of more

powerful yet cost-effective solutions, which inevitably increases implementation complexity and costs.

In addition to technical challenges, *the quality of teaching resources* is also an issue. Self-developed resources may vary in quality, making it difficult to meet professional standards. Furthermore, *low student engagement* is another concern, as some students may lack interest in virtual simulation training.

4.3. Measures

To address these challenges, several measures can be implemented:

Technical Training: Institutions can regularly host specialized workshops for teachers. These workshops can help educators improve their skills in VR technology and software operation while learning how to integrate new technologies effectively into teaching practices. Additionally, establishing teacher mutual support groups can encourage knowledge sharing and mutual improvement.

Hardware Support: Schools can invest in public training labs equipped with hardware that meets the requirements of virtual simulation software. This ensures that students lacking personal equipment can still participate in effective training. Schools may also collaborate with external organizations to share hardware resources, reducing costs and increasing utilization.

Software Optimization: Institutions can seek partnerships with professional software developers to co-develop or optimize software functionalities to meet teaching requirements. Such collaborations can involve schools providing teaching needs and developers offering technical support, resulting in user-friendly, efficient virtual simulation software tailored for educational purposes.

Resource Quality Assurance: Academic departments should establish rigorous review and evaluation mechanisms to regularly assess teaching resources. Teachers should be encouraged to actively participate in resource development and optimization through incentives such as rewards and recognition.

Enhancing Student Engagement: Teachers can design highly interactive and engaging activities, incorporating gamification, role-playing, and other creative methods to spark students' interest. Additionally, standardized assessment tools and indicators, combining qualitative and quantitative methods, should be developed to ensure objective and effective teaching evaluation.

Regular Updates and Maintenance: To ensure the continuous development of this training model, regular updates and maintenance of virtual simulation environments and teaching resources are necessary. This includes upgrading software and hardware, updating teaching content, and enriching training scenarios to maintain optimal operational status and provide high-quality learning experiences.

5. CONCLUSION

In conclusion, this low-cost and high-efficiency virtual simulation training model for crime scene investigation demonstrates significant advantages in enhancing teaching effectiveness, reducing training costs, and improving students' practical skills. By overcoming the time and space constraints of traditional training, this model enhances interactivity and realism, providing students with near-real-world experiences in a safe and controlled environment.

Although challenges such as technical barriers, hardware limitations, and software functionality exist, these issues are not insurmountable. Looking ahead, as VR technology continues to advance and educational concepts evolve, this training model is expected to play a greater role in fields such as criminal investigation, forensic medicine, and forensic science. It will support the cultivation of highly skilled professionals, equipping them to handle complex and

dynamic challenges in their careers.

Educators in relevant fields should continue exploring and practicing this model, making ongoing improvements in technology, content, and methodology to achieve sustained enhancement in teaching quality.

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Conflicts of interests

None declared.