ENHANCING BIOMEDICAL EDUCATION THROUGH INNOVATIVE VIRTUAL REALITY PLATFORMS: DEVELOPMENT AND ASSESSMENT OF A UNITY-BASED FORENSIC LABORATORY SIMULATION

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ABSTRACT

This research paper illuminates the growing necessity for innovative educational platforms in the biomedical field, given the burgeoning population and consequent demand for medical professionals. Proposing a novel solution, the project introduces a Virtual Reality (VR) application, designed using the Unity game engine, to foster scientific exploration within a simulated forensic laboratory environment [1]. Key components of the program include a VR Control System, accurate emulations of scientific equipment, and a cohesive puzzle design to drive user engagement and analytical thinking. Challenges such as VR controls comfort, environment scaling, and asset acquisition were navigated, enhancing the user experience. The application was subjected to user experimentation, particularly with high school students, through two distinct surveys assessing user experience and feedback for enhancements. Results indicated a notable engagement among the younger demographic with a demand for additional levels and specific improvements on equipment like the centrifuge [2]. The feedback gathered underscores the project's potential in revolutionizing biomedical education, providing an immersive, interactive, and enjoyable learning platform. By addressing the feedback and expanding the project further, the VR application holds promise in significantly contributing to the educational domain, preparing the next generation of medical professionals in a cost-effective and engaging manner.

KEYWORDS

VR Puzzles, Forensics, Investigations, Unity

1. INTRODUCTION

The pressing issue at hand is the scarcity of well-prepared professionals in the biomedical field, a sector crucial for human health and wellbeing. This deficit originates from a combination of an escalating global population, an aging populace necessitating more medical attention, and barriers to effective education and hands-on training for aspiring professionals. The historical pedagogical methodologies often involve direct interaction with complex and expensive laboratory equipment, under the supervision of seasoned professionals. However, these traditional methods are becoming increasingly inadequate to meet the burgeoning demand, exacerbated by the resource constraints many educational institutions face. The importance of resolving this dilemma cannot

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be understated as the ripple effects extend beyond the individual learner to society at large [3]. A shortfall in proficient biomedical professionals adversely affects the healthcare sector's capacity to provide timely and effective services. For instance, the Bureau of Labor Statistics projects a need for 12% more medical and clinical lab technicians between 2016 and 2026. The crux of the matter lies in devising innovative educational strategies that can bridge the knowledge and experience gap for budding biomedical professionals in a cost-effective and scalable manner. The methodologies drawn from the three different studies showcase a diverse spectrum of Virtual Reality (VR) applications aimed at addressing distinct challenges across various fields.

Method 1 by Plecher, Deterding, and Linehan (2020), emphasizes the utilization of Head-Mounted Display Virtual Reality (HMD-VR) in creating engaging therapeutic interventions [4]. However, it falls short in delivering a structured game design and overlooks narrative-driven experiences. In contrast, your project advances by offering a structured, narrative-driven, and problem-solving environment within a forensic lab, facilitating a more comprehensive learning experience.

Method 2 by Singh et al. (2020) explores VR as an educational tool for Biomedical Engineering (BME) students, specifically focusing on fostering communication skills for interprofessional collaborations. While it showcases VR's potential in simulating real-world clinical scenarios, it limits its scope to enhancing communication skills and understanding interdisciplinary collaboration. Unlike this methodology, your project presents a more holistic approach, offering an immersive forensic lab environment for hands-on interaction with scientific equipment and problem-solving puzzles, thus broadening the educational objectives within the biomedical field.

Method 3 by Lin et al. (2018) explores VR games as a conduit for enhancing healthcare experiences for individuals with chronic diseases. It emphasizes creating immersive environments for therapy, rehabilitation, and palliative care. Although impactful in the healthcare domain, this methodology diverges from your project's focus, which is to foster an educational and analytical environment within a forensic lab setting. Your project, hence, emphasizes the educational spectrum, providing hands-on experience with scientific equipment, and nurturing analytical thinking through puzzle-solving, showcasing VR's versatility in addressing unique challenges across diverse fields.

We propose leveraging virtual reality (VR) to foster a rich, immersive educational environment where students can interact with simulations of real-world biomedical equipment and scenarios. This approach not only circumvents the hefty costs associated with traditional lab equipment but also provides a safe, engaging platform for experiential learning. In our project, we have developed a VR setup using Unity, wherein the user steps into a virtual forensics' lab furnished with essential apparatuses like a microscope, centrifuge, and DNA analyzer. Through interactive puzzles and simulated analyses, students can scrutinize evidence and deduce a culprit, mirroring real-world forensic investigations. This hands-on experience, albeit in a virtual setting, is instrumental in demystifying complex biomedical procedures, fostering a deeper understanding, and enhancing retention. Compared to other methods such as video tutorials or static textbook content, our VR solution offers a more interactive and realistic experience. Furthermore, unlike conventional labs, our VR lab is accessible anytime and anywhere, removing geographical and time constraints [5]. Besides, the VR setup is easily replicable and can be updated or expanded with new scenarios and equipment, ensuring a continually evolving educational resource. Through this initiative, we aim to ignite curiosity and bolster the practical skills of aspiring biomedical professionals, thus contributing to alleviating the shortfall in qualified personnel in this vital sector.

In Section 4, we conducted two experiments to gauge the effectiveness and potential improvements for our VR project. The first experiment aimed to assess user feedback on the current experience, seeking to understand the strengths and weaknesses of the VR simulation. Through a structured survey, participants rated different aspects of the experience, from controls to puzzle design. The data revealed that the DNA Analyzer phase was the most engaging, while the centrifuge phase was identified as the least interesting, guiding us to areas needing improvement [6]. The second experiment aimed at understanding user preferences for future expansions. Through open-ended questions, we collected insights on desired features and identified areas of dissatisfaction. Participants expressed a desire for more levels, better interactivity, and the possibility of a collaborative mode. These findings were instrumental in understanding how well the project met its educational objectives and how it could be improved to better engage and educate users, especially concerning the centrifuge's functionality and the request for more intricate puzzles and levels.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Abrupt Movements

A pivotal component of our program is ensuring intuitive VR controls while maximizing user comfort. In VR environments, traditional input mechanisms can feel unnatural and may lead to discomfort or disorientation. For instance, abrupt movements or poorly mapped controls could potentially cause motion sickness, thus hindering the learning experience. Addressing this requires a well-thought-out design that closely mimics real-world interactions. One could use ergonomic design principles to create intuitive, comfortable control schemes. Additionally, incorporating feedback mechanisms like haptic feedback can enhance the user experience by providing a semblance of touch. Implementing adjustable settings to cater to individual comfort levels and preferences is also a viable solution. By thoroughly testing with a diverse group of users and iterating based on feedback, one could significantly enhance the controls and comfort, making the VR environment conducive to prolonged, engaging learning.

2.2. Inaccurate Scaling

Accurate environment scaling is critical to ensure a realistic and immersive experience. Inaccurate scaling can disrupt the user's immersion and potentially misrepresent the real-world equipment and space they are interacting with. To address this, one could employ precise measurements of actual lab equipment and spaces as a reference for creating the virtual environment. Additionally, consulting with biomedical professionals to ensure the accuracy and relevance of the scaling could be beneficial. Providing an option for users to adjust the scale to match their physical size and preferences could also enhance the realism and comfort of the VR experience.

2.3. Asset Acquisition

Asset acquisition, particularly obtaining good quality models of biomedical equipment and environment assets, is a substantial challenge. The success of the VR simulation heavily relies on the authenticity and detail of the assets to provide a genuine learning experience. One could collaborate with biomedical professionals and 3D modelers to create custom assets that accurately represent real-world equipment. Additionally, exploring open-source or commercially available asset libraries could be a viable way to acquire high-quality assets. Negotiating partnerships with biomedical companies for access to detailed 3D models of their products or even utilizing photogrammetry to create accurate 3D models from photographs are other potential strategies to address the asset acquisition challenge.

3. SOLUTION

The main component requirements for this project are the VR Control System, an accessible emulation of scientific equipment, and a cohesive puzzle design that can drive the user to properly interact with the systems available to them [7]. When the user opens the application, they are greeted by a tutorial at the entrance of the lab to get acclimated to the VR controls. The VR Control System must be good enough to avoid motion sickness and intuitive enough for the general user to be able to pick up on. Once the user is comfortable, they are then free to roam around the laboratory and will be greeted by a table with their objective in front of them. There is a variety of equipment that can be explored by the user to help them solve the mystery. To bring this system to reality, we are using the Unity game engine to power the environment the user will be interacting with.

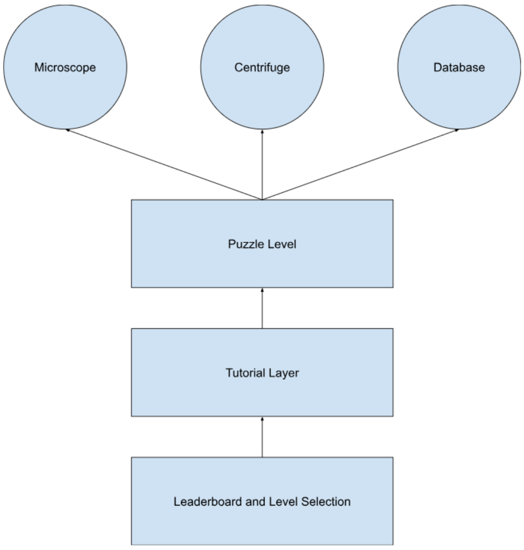

Figure 1. Overview of the solution

The VR Control System in the project is crucial for a seamless user experience, offering intuitive controls to avoid motion sickness, as demonstrated in the initial tutorial. It ensures users can interact with the virtual lab environment comfortably, fostering an engaging learning experience.

Figure 2. Screenshot of the system 1

```
float m_TimeMadeExclusive;

LocomotionProvider m_CurrentExclusiveProvider;


[SerializeField]

[Tooltip("The timeout (in seconds) for exclusive access to the XR Origin.")]

float m_Timeout = 10f;


/// <summary>

/// The timeout (in seconds) for exclusive access to the XR Origin.

/// </summary>

public float timeout

{

    get => m_Timeout;

    set => m_Timeout = value;

}


[SerializeField, FormerlySerializedAs("m_XRRig")]

[Tooltip("The XR Origin object to provide access control to.")]

XROrigin m_XROrigin;


/// <summary>

/// The XR Origin object to provide access control to.

/// </summary>
```

```
public XROrigin xrOrigin

{

    get => m_XROrigin;

    set => m_XROrigin = value;

}


/// <summary>

/// (Read Only) If this value is true, the XR Origin's position should not be
modified until this false.

/// </summary>

public bool busy => m_CurrentExclusiveProvider != null;


/// <summary>

/// See <see cref="MonoBehaviour"/>.

/// </summary>

protected void Awake()

{

    if (m_XROrigin == null)

        m_XROrigin = FindObjectOfType<XROrigin>();

}


/// <summary>

/// See <see cref="MonoBehaviour"/>.
```

```
/// </summary>

protected void Update()

{

    if (m_CurrentExclusiveProvider != null && Time.time > m_TimeMadeExclusive
+ m_Timeout)

    {

        ResetExclusivity();

    }

}


/// <summary>

/// Attempt to "lock" access to the XR Origin for the <paramref
name="provider"/>.

/// </summary>

/// <param name="provider">The locomotion provider that is requesting
access.</param>

/// <returns>Returns a <see cref="RequestResult"/> that reflects the status
of the request.</returns>

public RequestResult RequestExclusiveOperation(LocomotionProvider provider)

{

    if (provider == null)

        return RequestResult.Error;


    if (m_CurrentExclusiveProvider == null)

    {
```

```
        m_CurrentExclusiveProvider = provider;

        m_TimeMadeExclusive = Time.time;

        return RequestResult.Success;

    }


    return m_CurrentExclusiveProvider != provider ? RequestResult.Busy :
RequestResult.Error;

}


void ResetExclusivity()

{

    m_CurrentExclusiveProvider = null;

    m_TimeMadeExclusive = 0f;

}


/// <summary>

/// Informs the <see cref="LocomotionSystem"/> that exclusive access to the
XR Origin is no longer required.

/// </summary>

/// <param name="provider">The locomotion provider that is relinquishing
access.</param>

/// <returns>Returns a <see cref="RequestResult"/> that reflects the status
of the request.</returns>

public RequestResult FinishExclusiveOperation(LocomotionProvider provider)

{
```

```
    if (provider == null || m_CurrentExclusiveProvider == null)

        return RequestResult.Error;


    if (m_CurrentExclusiveProvider == provider)

    {

        ResetExclusivity();

        return RequestResult.Success;

    }


    return RequestResult.Error;

}
```

Figure 3. Screenshot of code 1

The provided code snippet outlines a system managing exclusive access to the XR Origin, ensuring controlled interactions within the VR environment. The LocomotionProvider class handles user movement, and exclusive access is required to prevent conflicting locomotion commands. The RequestExclusiveOperation and FinishExclusiveOperation methods are pivotal; they attempt to "lock" and "release" access to the XR Origin, respectively, for a particular LocomotionProvider [8]. The Update method continuously checks if the exclusive access timeout has been reached, resetting exclusivity if necessary. This setup ensures that only one locomotion provider can interact with the XR Origin at a time, minimizing potential issues like motion sickness due to conflicting movement commands, and thus enhancing user comfort and control intuitiveness.

The scientific equipment emulation provides a realistic, hands-on experience with essential biomedical tools like microscopes, centrifuges, and DNA analyzers. This component allows users to interact with virtual renditions of real-world equipment to solve puzzles, facilitating an immersive learning experience.

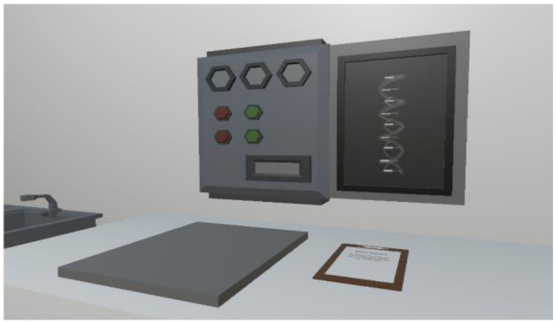

Figure 4. Screenshot of the system 2

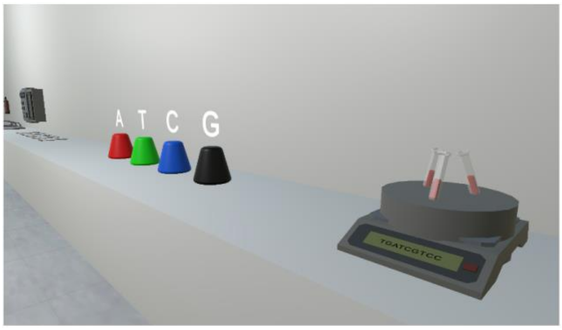

Figure 5. Screenshot of system 3

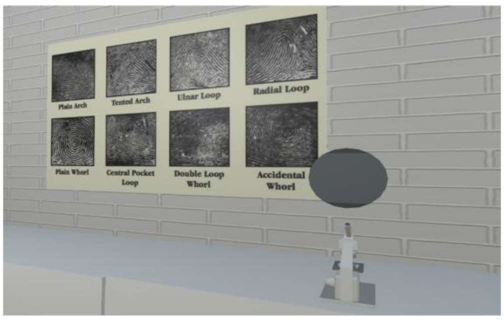

Figure 6. Screenshot of the system 4

```
void OnCollisionEnter(Collision collision)
{
    Debug.Log(collision.transform.GetChild(6).GetChild(0).name);
    if (collision.transform.GetChild(6).GetChild(0).name != null)
    {
        Debug.Log("Setting sequence");
        dnaColor.SetSequence(collision.transform.GetChild(6).GetChild(0).name);
    }
}
```

Figure 7. Screenshot of code 2

In this snippet, the OnCollisionEnter method is triggered when a collision occurs, presumably when a suspect clipboard is placed on the DNA analyzer's input tray. The method then retrieves a DNA sequence name from the collided object's hierarchy and passes it to a dnaColor object via the SetSequence method. This is a simplified yet effective way to emulate the process of loading a DNA sample into a DNA analyzer [9]. Through such interactions, users are exposed to essential steps involved in DNA analysis, making the virtual environment educational and reflective of real-world biomedical procedures.

The cohesive puzzle design guides users to interact with the available systems and equipment effectively to deduce a culprit. By engaging in these interactive challenges, users can better understand the practical applications of the scientific equipment while enjoying a captivating, mystery-solving experience within a virtual forensics lab.

Figure 8. Screenshot of the system 5

```
void OnCollisionEnter(Collision collision)
{
    if (verdict.activeSelf)
    {
        return;
    }
    if (collision.gameObject == solution)
    {
        Debug.Log("Correct!");
        this.GetComponent<MeshRenderer>().material = correct;
        verdict.transform.GetChild(0).GetComponent<TextMeshPro>().text = "Correct!";
        verdict.transform.GetChild(0).GetComponent<TextMeshPro>().color = Color.green;
    }
    else
    {
        Debug.Log("Incorrect!");
        this.GetComponent<MeshRenderer>().material = incorrect;
        verdict.transform.GetChild(0).GetComponent<TextMeshPro>().text = "Incorrect!";
        verdict.transform.GetChild(0).GetComponent<TextMeshPro>().color = Color.red;
    }
    verdict.SetActive(true);
}
```

Figure 9. Screenshot of code 3

The snippet demonstrates a correctness check within a puzzle scenario, triggered upon a collision event, presumably when a user submits a guess. The OnCollisionEnter method checks whether the collided object matches the solution. If it does, a "Correct!" message is logged, and visual feedback is provided by changing the material color to green and updating a text field. If incorrect, a similar but negative feedback is provided. This setup embodies a crucial aspect of puzzle design - immediate feedback, which is essential for user engagement and learning. Through such feedback, users can understand their actions' outcomes, promoting a trial-and-error approach to solving the puzzles and ultimately enhancing their understanding of the scientific processes involved.

4. EXPERIMENT

4.1. Experiment 1

Given that the main point of this project is to spur more interest in the medical field, the most prudent measure to take would be to evaluate user feedback on the current experience to get a better read on the strengths and weaknesses of the experience.

The primary objective of this experiment is to ascertain the effectiveness of the VR experience in igniting interest in the medical field among users. The setup entails administering a post-experience survey to participants, focusing on their perceptions of the VR environment, the learning curve, and the overall engagement in medical science fostered through the interactive puzzles and equipment use. The survey will be structured to capture both quantitative and qualitative feedback, allowing for a comprehensive understanding of the experience's strengths and weaknesses. Control data for the experiment will be sourced from existing literature on traditional biomedical educational methods, providing a baseline to compare the engagement and interest spurred by the VR experience.

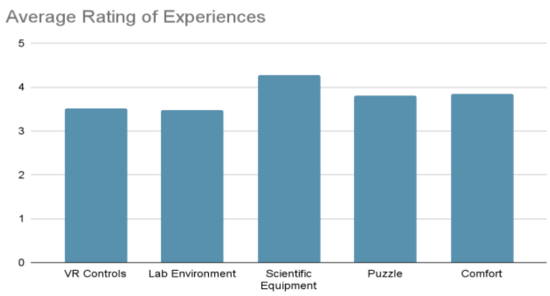

Figure 10. Average rating of experiences

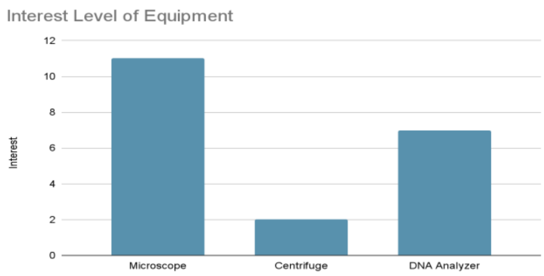

Figure 11. Interest level of equipment

The mean scores for VR Controls, Lab Environment, Scientific Equipment, and Puzzle are 3.5, 3.5, 4.3, and 3.8 respectively, with median scores of 3.5, 3.5, 4, and 3. The lowest value is 2 (for Puzzle) and the highest is 5 (for Scientific Equipment). The high rating for Scientific Equipment indicates that the realistic emulation of biomedical apparatuses is well-received. However, the Puzzle category scored lowest, suggesting that the puzzle design needs improvement to enhance user engagement and challenge. Despite being the final and presumably most challenging phase, the DNA Analyzer was not the phase where most got stuck, which was unexpected. Instead, Phase 2 (Centrifuge) was where most respondents got stuck, potentially indicating that it might lack clarity or engagement despite its simplicity. The data suggests that while the simulation's realistic equipment and lab environment are strengths, the puzzle design, particularly the Centrifuge phase, needs re-evaluation to prevent user frustration and enhance the learning and engagement aspect of the experience. Enhancing clarity and engagement in the puzzle, especially in the Centrifuge phase, could potentially lead to a more enriching user experience.

4.2. Experiment 2

For the future outlook of the experience, we also need to determine what kind of feature set users will want to see in order to continue ongoing interest in the project itself. Looking ahead towards evolving the VR project, it is crucial to align development with user expectations and preferences. This experiment will involve a feedback survey encompassing questions regarding desired features, level of complexity, and the variety of scientific equipment they wish to interact with in future iterations. The survey will also include open-ended questions for additional suggestions and features that could sustain and enhance their interest in the project. The setup aims to garner insight into user expectations, thereby guiding the future development of the project to ensure it continues to captivate interest and fulfill its educational objectives. Comparative analysis will be done using feedback from the first experiment to understand the progression of user expectations and satisfaction.

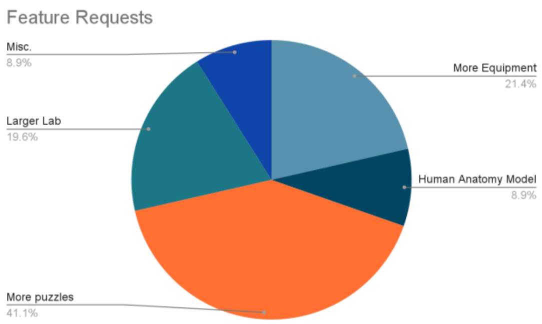

Figure 12. Feature requests

In analyzing the feedback from the second survey, several themes emerge that point towards potential areas of improvement and expansion for the project. Respondents expressed a desire for more levels and puzzles, indicating an engagement with the core mechanics of the project and a wish for more content. A notable number of participants found the centrifuge phase to be the least engaging, which aligns with the feedback that the centrifuge was the least interesting piece of equipment. Suggestions for improvement largely centered around enhancing the interactivity and realism of the scientific equipment, with particular emphasis on the centrifuge. Additionally, the idea of a multiplayer or collaborative mode was raised, hinting at a potential avenue for expanding the project in a way that might foster cooperative learning and problem-solving. The responses to the open-ended questions about disliked elements and suggestions for improvement provide a useful roadmap for refining the existing content and expanding the project in future iterations. The feedback underscores the importance of balancing realism and educational content with engaging gameplay and user-friendly controls to provide a satisfying and instructive user experience.

5. Related Work

Plecher, D., Deterding, S., and Linehan, C. delves into the realm of HMD-VR health games, aiming to foster engagement with therapeutic interventions through game-based formats (Plecher, Deterding, & Linehan, 2020) [11]. The solution revolves around utilizing HMD-VR technology to create immersive games, mainly targeting physical exercise, motor rehabilitation, and pain management. While effective in creating engaging environments, the solution's limitation lies in its lack of a structured game design approach, often lacking detailed articulation. The discourse primarily revolves around physical health contexts, ignoring narrative-driven experiences and non-physical exercise interventions. Unlike this approach, our project advances by offering a narrative-driven, problem-solving environment within a forensic lab setting. By emulating real-world biomedical equipment and procedures, your project potentially provides a more structured, engaging, and educational experience. Furthermore, your project's focus on analytical thinking and problem-solving could offer a more enriched learning experience compared to the more generic game design discussed in the source.

The study conducted by Singh et al. (2020) delved into the potential of virtual reality (VR) as an educational augment for biomedical engineering (BME) students, with a focus on honing communication skills essential for interprofessional collaborations in clinical settings [12]. Through a comparison of VR and traditional two-dimensional (2D) videos, the study illustrated that VR videos fostered a deeper sense of immersion and a better understanding of interdisciplinary teamwork dynamics among BME students. The feedback garnered from students, especially those with prior in-person immersion experience, showcased VR as a promising alternative for real-world clinical scenario immersion. The study concluded that VR stands as a robust educational tool capable of simulating clinical scenarios effectively, preparing BME students for interprofessional interactions in real-world clinical settings. However, the study's scope appeared to be limited to enhancing communication skills and understanding of interprofessional collaboration, potentially overlooking other pivotal aspects of biomedical engineering education. In contrast, your project takes a more holistic approach by offering an immersive forensic lab environment where users can interact with scientific equipment and engage in problem-solving puzzles. This not only simulates real-world scenarios but also provides hands-on experience with scientific equipment, thereby potentially offering a more comprehensive and enriched educational experience to users. This underscores a significant stride in utilizing VR for a broader spectrum of educational objectives within the biomedical field.

Lin et al. (2018) explore the burgeoning domain of Virtual Reality (VR) games as a conduit for enhancing healthcare experiences, particularly for individuals with chronic diseases [13]. The paper underscores the ability of VR to provide immersive and interactive environments, thereby transforming traditional healthcare paradigms. Through advanced input and output devices rendering three-dimensional (3D) graphics, VR successfully mimics real-world sensory information, offering users an enriched interface to interact with. The paper delineates how VR games have transcended the entertainment realm, finding applications in therapy, pain relief, surgical procedures, patient education, and rehabilitation, among others, significantly improving healthcare quality and accessibility.

The crux of the paper orbits around a VR game design proposed for rehabilitation and palliative care, aimed at ameliorating the quality of life for individuals living with chronic diseases. The

VR game aspires to provide an alternate environment for individuals, especially those with physical limitations, enabling them to engage in activities otherwise inaccessible to them, such as running or jumping. This VR interaction is envisioned to not only uplift their mood but also impart crucial lessons regarding managing chronic illnesses and reinforcing health maintenance messages.

Contrastingly, your project delves into a different facet of VR applications, focusing on creating an educational and problem-solving environment within a forensic lab setting. Unlike the healthcare-focused approach of Lin et al. (2018), your project aims to enrich the educational spectrum, providing hands-on experience with scientific equipment and fostering analytical thinking through puzzle-solving. This divergence showcases the vast potential and versatility of VR applications across diverse fields, each addressing unique challenges and augmenting user experiences in its distinctive way.

6. CONCLUSIONS

The current iteration of our project showcases a promising venture into melding VR with scientific exploration; however, certain limitations are discernible. Primarily, the singular level available restricts the breadth of exploration and learning experiences. Moreover, the provision of only three pieces of equipment may limit the variety and depth of practical knowledge users can garner. The lack of additional simulations, such as fluids, further curtails the realism and the range of scientific scenarios that users can engage with. Lastly, the general asset quality could be honed to enhance the immersion, rendering a more realistic and engaging user experience.

With more time, these limitations could be addressed progressively. Firstly, developing additional levels with varied objectives and complexities would enrich the learning and exploration avenues [14]. Secondly, incorporating a wider array of equipment and simulations would deepen the practical knowledge and engagement users could obtain. Thirdly, improving asset quality through higher-resolution textures, realistic lighting, and possibly even integrating haptic feedback could significantly uplift the level of immersion and user satisfaction. Lastly, extending the simulation to encompass fluid dynamics would also provide a more comprehensive and realistic virtual laboratory experience. Through these enhancements, the project could evolve into a more robust, engaging, and educative platform that effectively encourages scientific exploration using VR.

The project successfully showcases the potential of integrating Virtual Reality (VR) in creating an engaging educational platform for scientific exploration [15]. While the current limitations narrow the scope, the groundwork laid provides a robust foundation for future expansions. With further development, this initiative could revolutionize how learners interact with scientific concepts and equipment, making education more interactive, immersive, and enjoyable.

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