

Some results of new training contents based on VR and 3D/360

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Abstract— In the era of knowledge-based development, the quality of education plays a pivotal role in shaping national progress. Among the numerous factors influencing educational quality, access to instructional resources, technological infrastructure, and laboratory environments is particularly significant. This paper presents the development and integration of interactive digital learning materials, including non-immersive and fully immersive Virtual Reality (VR) simulations, as part of virtual laboratory solutions.

The proposed educational tools incorporate 2D and 3D models, 360-degree panoramic images, instructional videos, augmented and virtual environments, and 3D animations. These contents deliver theoretical explanations, equipment demonstrations, and guided instructional materials, enabling learners to perform simulations, hands-on activities, and laboratory exercises using VR-based technologies. In fully immersive environments, learners gain a heightened sense of presence, which enhances engagement and improves learning outcomes.

The study explores the application of the developed materials across education, healthcare, and other scientific domains. By employing 360-degree domes, interactive 3D content, and VR simulations, the research investigates the potential to replace complex physical laboratories with accessible, cost-effective virtual alternatives. The core objective of this work is to offer an innovative instructional approach by virtualizing traditionally resource-intensive learning environments. The paper outlines our technical framework and development process for designing and deploying these digital educational resources and virtual laboratories.

Keywords— Information Technology, virtual reality (VR), virtual environment, 360 image, video, web content, 3D interactive animation

I. INTRODUCTION

Among the numerous factors influencing the quality of education, the learning environment and instructional resources play a critical role. A key responsibility of higher education institutions is the continuous enhancement and modernization of digital educational tools and laboratory infrastructure, which are essential components of the learning environment. Various elements—including societal progress, digital transformation, institutional funding capacity, and classroom accessibility—affect the effectiveness of educational settings. As a result, integrating advanced information technologies into pedagogy and promoting the widespread use of digital educational resources across all educational levels and disciplines have become increasingly viable. The application of virtual environments in education is now well-documented globally.

The growing adoption of information technologies has led to their deep integration into daily life. Notable developments include the use of 360-degree imagery and video for virtual tours and marketing, along with the increasing availability of VR and MR technologies for creating immersive environments. In this context, we are developing web-based interactive educational materials for MOOCs, incorporating 360-degree domes and 3D animations. The accessibility of 360° cameras such as Insta360, GoPro, Ricoh, Kandao, and Samsung Gear, along with Head-Mounted Display (HMD) devices, enhances the immersive realism of virtual environments.

Although the concept of virtual reality (VR) was first articulated in 1992, its advancement was initially hindered by high costs and technical complexity. The theoretical foundation traces back to Charles Wheatstone's 1838 discovery that the human brain synthesizes two distinct images perceived by each eye into a single three-dimensional object. His invention, the stereoscope, enabled users to view dual images with a profound sense of depth and realism. Later, in the 1860s, panoramic wall art emerged as an early form of 360-degree representation, further grounding the idea of virtual experience. By the 1970s, the term artificial reality had been introduced to describe such immersive systems.

In recent years, consumer VR technologies such as Meta Quest, Samsung Gear, HTC VIVE, and OSVR have rapidly gained popularity. Platforms like Facebook 360 and YouTube 360 now offer fully immersive content experiences. These entertainment-driven technologies are increasingly being adopted in education and scientific fields, demonstrating significant potential for pedagogical and interdisciplinary application.

II. RELATED WORKS

Recent advancements in immersive technology have enabled more dynamic and interactive educational experiences across disciplines. In the domain of dental and medical education, Farronato et al. (2019) conducted a comprehensive systematic review on the use of augmented reality (AR) for clinical and educational applications in dentistry. Their review analyzed 33 studies, highlighting the growing trend of using AR systems—both head-mounted and camera-display configurations—for tasks ranging from oral surgery to orthodontic education. The studies demonstrated encouraging results in terms of spatial accuracy and learning enhancement, though some also noted extended preparation time when integrating AR into clinical procedures. [1]

Complementing this perspective, Choi et al. (2018) explored the design of mobile-based 360° VR learning scenarios for marine biology education. Their work emphasized the benefits of a multilayer VR content architecture that supported deformable object interaction and realistic simulations, such as water effects. The findings from their user studies indicated that such interactive 360° VR experiences on mobile platforms significantly improved learners' sense of immersion and motivation, supporting the premise that immersive digital environments can effectively augment traditional education. [2]

Rosendahl and Wagner (2023) further expanded this discussion with a systematic review of 360° video applications in education. Drawing from 44 peer-reviewed articles, they categorized the educational benefits of 360° videos into five domains: increased motivation, authentic and realistic learning environments, immersive interaction, multi-perspective content observation, and individualized learning experiences. Their study emphasized that although 360° videos lack the programmability of full VR, they offer a cost-effective, resource-efficient method to achieve high levels of engagement—particularly when integrated with head-mounted displays or mobile playback tools. [3]

The convergence of 360° video and virtual/augmented reality in education reveals an emerging focus on learner engagement, spatial understanding, and experiential learning. Particularly relevant to virtual laboratory environments, the interactive design elements explored by Choi et al. (2018)—such as object deformation and real-time feedback—mirror the essential components needed for scientific simulations, reinforcing the transferability of immersive technologies across disciplines.

Additionally, the literature highlights a shift toward user-generated content in immersive education. Choi et al. (2018) demonstrated how learners could co-create mobile VR content using a lightweight framework, suggesting a move toward constructivist learning models. This aligns well with virtual laboratory settings, where exploratory behavior and learner autonomy are key outcomes.

Rosendahl and Wagner's findings also underscore the distinction between 360° video and full VR, advocating for clearer taxonomy when describing virtual learning media. Their review found that 360° videos are particularly effective in supporting observational learning and theory-practice integration—both central to virtual laboratory environments where students must connect abstract scientific principles with simulated hands-on tasks.

Taken together, these studies reinforce the growing validation of immersive learning technologies across diverse educational contexts. They provide a foundational basis for extending immersive approaches to virtual laboratory applications, where cost-efficiency, interactivity, and immersive engagement are essential design considerations.

III. RESEARCH METHODOLOGY

Since the early 2000s, the Mongolian University of Science and Technology (MUST) has been actively involved in the development of distance and digital learning resources. Several national initiatives were implemented by the government to support the expansion of e-learning. Notable among these are the National Distance Education Program

launched in 2002, the E-Mongolia National Program (2005–2012), and the One Mongolia Initiative (2012–2016).

In recent years, e-learning has undergone significant development, expanding across various disciplines through the integration of digital technologies and open education principles. Since 2010, our institution has focused on the design and research of virtual laboratories, producing two-dimensional (2D) and online interactive digital learning materials that have been integrated into university-level instruction. In alignment with Resolution No. 67, which mandated the digital transformation of master's-level courses, approximately 260 e-learning courses and around 10 virtual laboratories were developed.

Examples include virtual laboratories designed for courses such as Construction Materials and New and Renewable Energy, which have been utilized to enhance the delivery of practical and theoretical content.

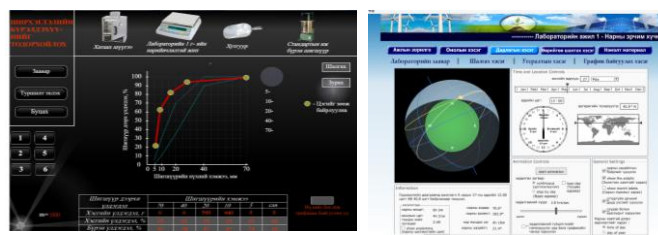


Fig. 1. Virtual Laboratories for the Courses "Building Materials" and "New and Renewable Energy Resources"

Following earlier efforts, educational tools and virtual laboratories have been developed using open-system web technologies and Virtual Reality (VR)-based platforms. These materials maintain a consistent structural framework to ensure coherence and usability across different applications.

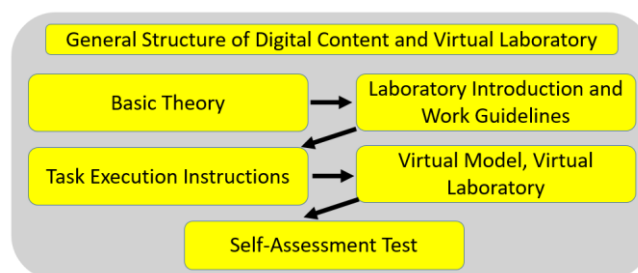


Fig. 2. General structure for development

A variety of interactive digital content has been designed to suit users of varying ages and cognitive levels. These include:

- Online simulations of financial systems;
- Interactive content tailored for young learners;
- Web platforms featuring 360° immersive domes;
- VR-based laboratory simulations for chemistry lessons involving chemical reactions and identification processes;
- Hybrid immersive environments that combine 360° panoramic imagery with 3D virtual settings;

- 360° and 3D simulations for protein identification in chemistry and biology courses.
- In the healthcare sector, particularly in the field of dentistry, VR-based virtual laboratory content has been developed for simulation of dental extraction procedures using 360° and 3D educational tools.



Fig. 3. Program start page

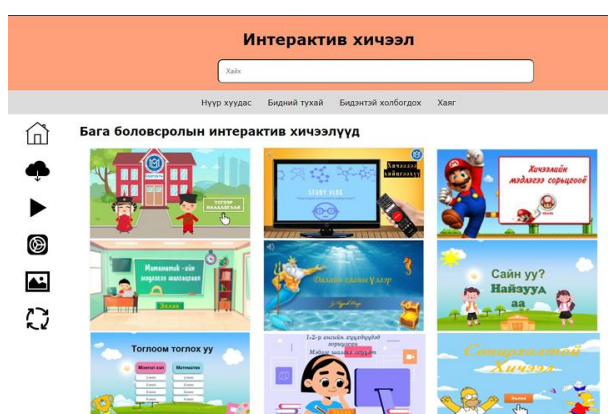


Fig. 4. Interactive electronic website for primary school lessons

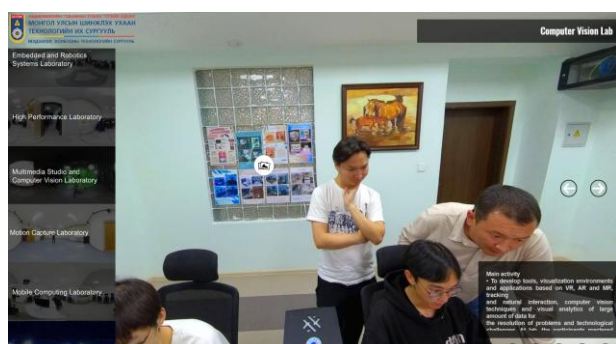


Fig. 5. MUST Virtual Tour Website



Fig. 6. 360° Video Virtual Environment



Fig. 7. Virtual Chemistry Laboratory 3D Model



Fig. 8. 3D Model of Protein Determination Laboratory

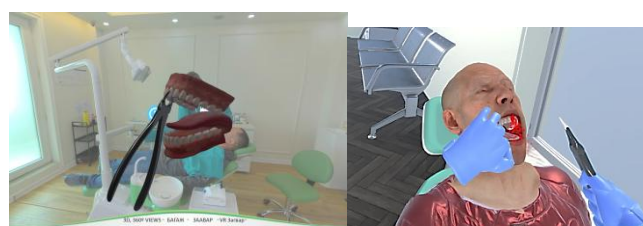


Fig. 9. Oral and Dental Medicine Electronic Content

As part of this research, we successfully completed the development of educational resources specifically designed for dental science, utilizing VR technologies. The project resulted in the creation of three types of digital content and simulation platforms:

- A fully immersive VR simulation compatible with Meta Quest 3 headsets;
- A web-based 3D interactive interface embedded with 360° virtual environments;
- A VR dome experience also configured for the Meta Quest 3 platform.

These three components—VR simulation, 360° digital environment, and virtual dome—were systematically designed and developed. Content creation for any virtual laboratory involves careful scripting and sequencing. Accordingly, the project followed a structured workflow, which included the production of annotated scripts, process mapping, and the integration of multimedia resources such as videos, audio guides, and illustrations. A 3D model of a dental clinic environment was created, and 360° imagery was captured on-site to replicate realistic clinical settings within the VR space. The result is a comprehensive VR and 360° digital content package that simulates real-world dental procedures.

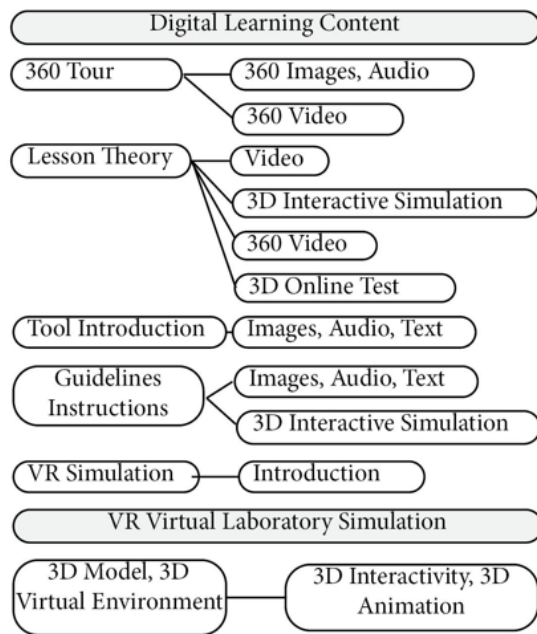


Fig. 10. Electronic Content Structure and File Organization

VR, AR (Augmented Reality), MR (Mixed Reality), and XR (Extended Reality) technologies have recently emerged as transformative tools in the entertainment sector. However, their application has rapidly expanded into education, business marketing, and scientific domains, revealing significant interdisciplinary potential. While 3D-rendered virtual environments offer flexible visualization, they often lack photorealism. As a result, the use of real 360° images and videos has become increasingly common in recent years.

VR-based systems are generally categorized into three levels of immersion:

- Non-immersive;
- Semi-immersive;
- Fully immersive.

Currently, 360° video and imagery are frequently utilized in semi-immersive and fully immersive VR platforms for applications such as marketing, entertainment, virtual tourism, and museum experiences.



Fig. 11. 360° Image

A. 360-degree video/image

360-degree videos and images capture visual information in all directions, allowing users to explore the surrounding environment from a full spherical perspective. These media files are typically stored in an equirectangular format and, during post-processing, are converted into a segmented

spherical view using CrystalView technology. This transformation aligns with the human field of vision, enhancing the immersive experience for the user [4].

In effect, users can perceive the scene as if they are inside a spherical environment. The content can be experienced in two primary ways:

- Through standard displays, enabling 360-degree interactive rotation via screen manipulation;
- Via Virtual Reality (VR) headsets (e.g., Meta Quest), which provide a more immersive and realistic viewing experience.

When viewed using a VR headset, users are fully immersed in the environment, producing a heightened sense of presence and realism that significantly enhances engagement.

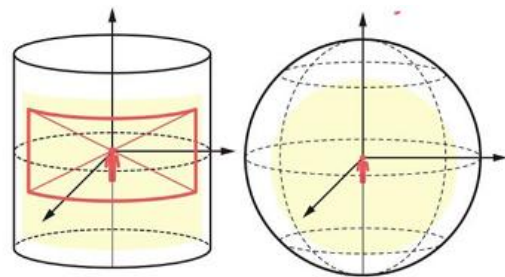


Fig. 12. Panorama Viewing Angle, 360° Environment



Fig. 13. 360° Virtual Environment Human Field of View

B. Virtual Reality environment

In the context of VR development, the virtual environment is a fundamental component. It encompasses all visible objects and spatial configurations perceived through the user's visual field. It is important to distinguish between the terms virtual reality (VR) and virtual environment. A virtual environment refers specifically to simulated settings that represent distant or inaccessible physical locations, often constructed using 360-degree imagery to achieve realism.

There are two primary methods for creating VR environments:

- Designing fully rendered scenes using 3D graphics software;
- Constructing environments from 360° images or videos.

The selection of either method depends largely on the intended purpose of the VR application:

- 3D graphics are preferred for building interactive VR experiences such as animations, simulations, films, and games;

- 360° imagery and video are more suitable for developing static VR environments used in advertising, marketing, social media, and virtual tours [5].

The educational content developed in this study employs a hybrid approach, combining both techniques to optimize realism and interactivity. Specifically:

- The theoretical and instructional content is presented within realistic 360° virtual environments;
- The dental extraction simulation component is developed using a 3D interactive VR environment.

To fully implement both 360° and 3D environments in an immersive VR context, several technical components and devices are required, including appropriate user interfaces and compatible head-mounted display (HMD) systems.

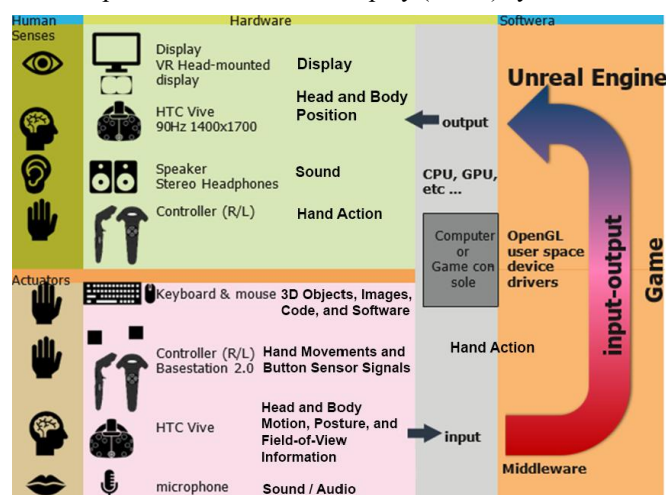


Fig. 14. VR Interface for Entering Reality

Immersive Virtual Reality (VR) environments rely on an ecosystem of hardware and software components to enable realistic interaction. A complete VR system typically involves a head-mounted display (HMD), motion- and sound-sensitive cameras, and handheld controllers. These devices collectively capture user input—such as visual direction, gestures, and actions—which are processed by the system and transmitted back as outputs to the HMD and peripheral devices. This cycle allows users to perceive and interact with the virtual environment in real time [6].

In essence, a VR system consists of three fundamental components:

- The user – provides sensory input and receives perceptual feedback;
- Hardware – captures input and delivers output signals;
- Software – performs processing, interaction programming, and simulation management.

C. Digital Content Development Technological Implementation

- The proposed digital content was developed using both 3D and 360° web technologies. Web-based interactive content was created using frameworks

such as Three.js, enabling immersive 3D animations directly in browsers.

- VR environments and 3D models were designed using tools such as Blender and Maya, while the simulations were developed using the Unity3D game engine.

D. Virtual Environment Design

The virtual environments were fully modeled in 3D, with detailed objects and animated sequences. The development process included:

- Construction of 3D virtual spaces;
- Creation of realistic 3D objects.



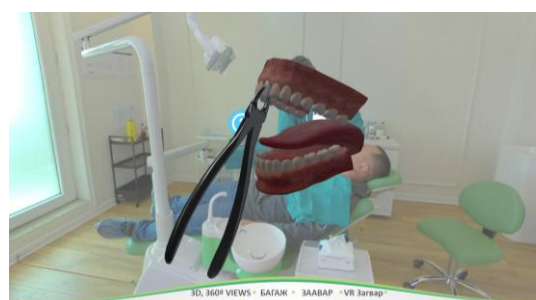
Fig. 15. Example of a figure caption. (figure caption)

In alignment with project goals, the digital learning modules were delivered in two primary formats:

- VR Dome Format – utilizing immersive HMD-based environments;
- 3D/360° Web-Based Interactive Content – accessible via standard browsers.



Fig. 16. 360° Electronic Content



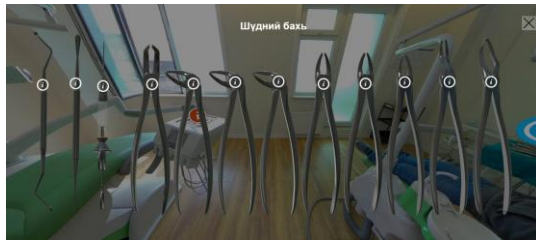


Fig. 17. 360° Electronic Content with 3D Animation

E. Interactive Testing Features

To support instructional effectiveness, an assessment module was integrated into the digital content. Unlike traditional question-answer formats, the test leverages 3D models and 360° virtual environments to promote engagement and interactive learning. The interface supports:

- Integration of 360° imagery and video;
- Audio narration;
- Embedded animations and interactive 3D elements.



Fig. 18. 3D 360° Electronic Content Test Section

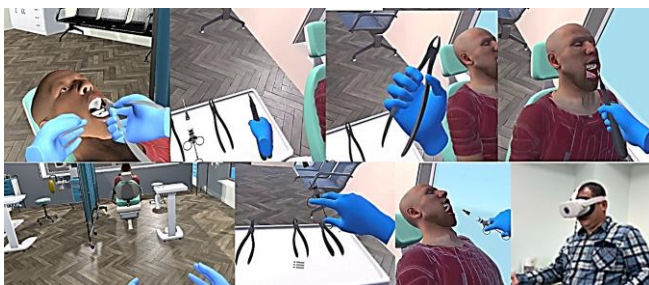


Fig. 19. 3D VR Tooth Extraction Simulation

F. VR-Based Tooth Extraction Simulation

A tooth extraction simulation was developed using the Unity3D engine, designed to run on VR headsets with hand tracking capability. The simulation enables interactive actions within a realistic 3D dental clinic. During development, over 1,000 lines of code were written to integrate custom actions, animations, characters, and environmental assets. The system architecture supports:

- Realistic hand-based manipulation via hand tracking;

- High-fidelity 3D models and animations;
- User immersion and procedural learning.

This VR laboratory models the entire tooth extraction procedure and provides a robust platform for continued expansion. The underlying software and 3D environment provide a foundation for further development and medical simulation training.

G. Pilot Study and Evaluation

In the field of medical and dental education, a user study was conducted to evaluate the effectiveness of educational tools based on 3D and 360° digital content and practical VR simulations. The study involved a total of 67 and 51 senior-year students, respectively. Similar research has been conducted in the field of health sciences, where immersive technologies such as virtual and augmented reality have been shown to enhance learning outcomes and student engagement. Moro et al. (2017) investigated the effectiveness of VR and AR tools in anatomical education and found significant improvements in spatial understanding and knowledge retention among students [7]. In a broader context, Radianti et al. (2020) systematically reviewed immersive VR applications in higher education and identified key design elements and pedagogical benefits that contribute to effective learning environments [8]. These studies support the growing use of 3D, 360° content, and simulation-based tools in education, providing a relevant foundation for virtual laboratory development in other disciplines.



Fig. 20. Questionnaire for Use in VR-Based Training

IV. VR RESULTS AND DISCUSSION

A. AHP-Based Weight Analysis for VR Educational Content

The Analytic Hierarchy Process (AHP) was applied to evaluate six critical factors influencing the effectiveness of virtual reality (VR)-based educational content.

These criteria included:

- 1) User Satisfaction
- 2) Learning Outcome
- 3) Assessment
- 4) Content Quality
- 5) User Interface
- 6) VR Design

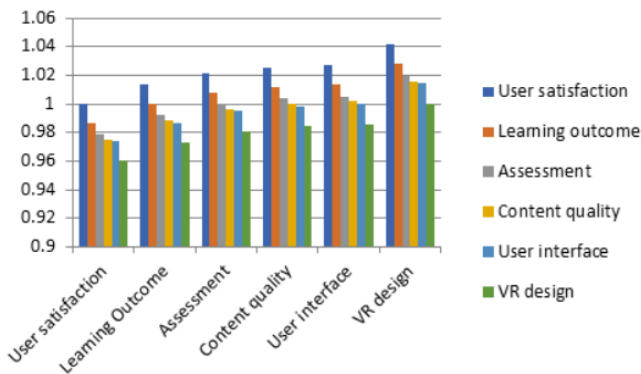
A pairwise comparison matrix was constructed using expert judgment, and normalized weights were calculated using the eigenvalue method. Table 1 summarizes the resulting priority weights assigned to each criterion.

TABLE I. PAIRWISE MATRIX

Table Head	Criteria	Normalized Weight (VR)
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Table Head	Criteria	Normalized Weight (VR)
1	User satisfaction	0.169
2	Learning Outcome	0.168
3	Assessment	0.166
4	Content Quality	0.166
5	User Interface	0.165
6	VR Design	0.165

a. Actual values are based on computation from the uploaded matrix and may vary slightly based on rounding.



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Fig. 21. Priority weight

The results indicate that user satisfaction (0.169) and learning outcome (0.168) received the highest relative weights among the criteria, suggesting that these are the most influential factors in evaluating VR-based learning experiences. These findings align with prior research emphasizing the importance of user engagement and perceived educational value in immersive learning environments.

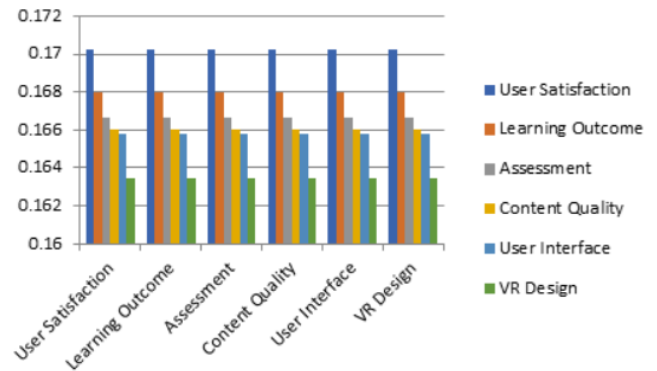
Interestingly, VR design (0.165) and user interface (0.165) received slightly lower but nearly equal weights, indicating that while technical design and interface are crucial, they are perceived as slightly less critical than pedagogical outcomes. Assessment (0.166) and content quality (0.166) were valued moderately and reflect a balanced perspective on instructional integrity and evaluation mechanisms in immersive contexts.

The relatively uniform distribution of weights across all six criteria suggests that a holistic design approach is necessary for VR-based educational systems. Developers and instructional designers should not only prioritize immersive technology but also ensure pedagogical soundness, user-centered interaction, and effective feedback mechanisms.

B. Normalized Pairwise Comparison Matrix

Table 2 presents the normalized pairwise comparison matrix derived from the Analytic Hierarchy Process (AHP) analysis for the VR-based learning environment. Each value represents the relative contribution of a criterion to the overall priority calculation. The normalization was performed by dividing each cell in the matrix by the sum of its corresponding column.

This process enables the standardization of expert judgments and ensures the resulting weights reflect a consistent and rational decision-making structure.



b. Each column sums to 1, satisfying the AHP normalization condition.

Fig. 22. Priority weight

The normalized matrix reveals that User Satisfaction consistently holds the highest normalized values (approximately 0.1702), followed closely by Learning Outcome (0.1680). This suggests that, across all pairwise comparisons, expert evaluators consistently rated satisfaction and learning impact as slightly more influential than the other criteria.

Conversely, User Interface (0.1658) and Content Quality (0.1660) exhibit marginally lower normalized contributions, though the differences are minimal. The closeness of all values reflects a balanced prioritization, indicating that all six factors are deemed critical in the context of VR-based education, with no single factor dominating the decision framework.

This consistency supports the reliability of expert judgment and indicates that the VR learning model requires a well-rounded design strategy that integrates instructional quality, interface usability, assessment effectiveness, and immersive design elements.

C. Priority Vector from AHP Analysis (VR Sheet)

The priority vector, derived from the normalized pairwise comparison matrix using the Analytic Hierarchy Process (AHP), represents the relative importance of each criterion in the VR-based educational system. The priority vector is calculated by averaging each row of the normalized matrix, which reflects the cumulative contribution of each factor across all pairwise judgments.

The resulting priority weights for each criterion are presented in Table 3.

TABLE II. PRIORITY WEIGHTS

Table Head	Criteria	Priority vector	Priority
1	User satisfaction	0.170220796	1
2	Learning Outcome	0.167956218	2
3	Assessment	0.166635214	3
4	Content Quality	0.166006165	4

Table Head	Criteria	Priority vector	Priority
5	User Interface	0.165754545	5
6	VR Design	0.163427062	6

^c The priority weights are consistent with the normalized matrix and reflect the overall significance of each criterion.

The priority vector indicates that User Satisfaction (0.1702) is considered the most critical factor in evaluating the effectiveness of VR-based educational environments. This aligns with learner-centered design principles that emphasize usability, engagement, and motivation as key success indicators.

Learning Outcome (0.1680) also holds high priority, affirming the educational value and instructional efficacy of the VR system. These two criteria collectively reflect the dual emphasis on user experience and pedagogical impact.

Other criteria—including Assessment, Content Quality, User Interface, and VR Design—received nearly equal weights (ranging from 0.1658 to 0.1666). This balance suggests that while user satisfaction and learning outcome are slightly prioritized, a holistic approach encompassing instructional design, user interaction, and technical implementation is essential for optimal system performance.

The distribution of weights indicates a well-rounded evaluation by expert participants, with no extreme bias toward a single criterion. This provides strong support for using AHP in educational technology research where multiple qualitative and quantitative factors must be harmonized.

Future development efforts should focus on optimizing both learner experience and instructional output, while maintaining high standards across all evaluated dimensions. Moreover, regular updates to the weighting scheme can help accommodate evolving user expectations, technological capabilities, and curriculum requirements.

1) *Objective of the Analysis:* The purpose of this Analytic Hierarchy Process (AHP) analysis was to rank the primary factors influencing the quality of VR-based education based on user evaluation data. AHP was used to objectively compare six key criteria using pairwise comparisons, with judgments collected on a 10-point scale and converted into a structured decision matrix.

2) *Evaluation Criteria:* The analysis included the following six primary criteria:

- a) *Content Quality*
- b) *VR Design*
- c) *User Interface*
- d) *Assessment*
- e) *Learning Outcome*
- f) *User Satisfaction*

Each criterion was evaluated using user-assigned scores and supported by sub-indicators where applicable, enabling a more granular assessment of educational value within VR environments.

3) *Weight Calculation and Prioritization:* The relative importance of each criterion was computed using the

standard AHP weighting procedure, including matrix normalization and derivation of the priority vector. Table 1 presents the resulting weights.

TABLE III. PRIORITY VECTOR

No	Criteria	Weight (%)
1	User Satisfaction	17.0%
2	Learning Outcome	16.8%
3	Assessment	16.7%
4	Content Quality	16.6%
5	User Interface	16.6%
6	VR Design	16.3%

The highest priority was assigned to User Satisfaction, indicating that learners value their experience and the perceived usability of VR educational content above other considerations. This is followed closely by Learning Outcome and Assessment, which underscores the significance of measurable academic performance in evaluating VR's instructional value.

The relatively narrow spread of the weights (ranging from 16.3% to 17.0%) highlights that all criteria are perceived as important, with no outliers or disproportionately weighted elements. This reinforces the need for a balanced and comprehensive development approach.

4) *Consistency Validation:* To verify the reliability and logical coherence of expert judgments, a Consistency Ratio (CR) analysis was conducted:

TABLE IV. CONSISTENCY RATIO

No	Metric	Value
1	Maximum Eigenvalue (λ_{max})	≈ 6.04
2	Consistency Index (CI)	≈ 0.008
3	Random Index (RI)	1.24
4	Consistency Ratio (CR)	≈ 0.006

Given that $CR < 0.1$, the results are considered logically consistent and statistically acceptable. This indicates that the decision-makers maintained high internal agreement during pairwise comparisons, making the priority weights trustworthy for academic and design decisions.

The analysis revealed User Satisfaction as the most influential factor, indicating that emotional engagement, ease of use, and positive perception are critical success factors for VR learning platforms. The high ratings for Learning Outcome and Assessment also validate the instructional effectiveness of the medium.

While all criteria received similar weights, the slightly elevated importance of satisfaction suggests that future VR system enhancements should prioritize user-centered design features that enhance motivation, comfort, and retention.

This AHP-driven approach provides an evidence-based framework for curriculum developers, instructional designers, and technology planners to optimize VR learning

environments in line with user expectations and educational objectives.

V. 360° WEB RESULTS AND DISCUSSION

A. AHP Results from 3D-Based Educational Content

To evaluate the effectiveness of 3D-based educational materials, the Analytic Hierarchy Process (AHP) was used to construct a pairwise comparison matrix comprising five key decision criteria. These included:

- 1) *User Satisfaction*
- 2) *Learning Outcome*
- 3) *VR Design*
- 4) *Content Quality*
- 5) *Assessment*

Each criterion was compared pairwise by experts, and the resulting judgments were normalized to derive priority weights using eigenvalue-based methods. The normalized results are shown in Table 5.

TABLE V. NORMALIZED RESULT

No	Criteria	Priority Weight (3D)
1	User Satisfaction	0.1756
2	Learning Outcome	0.1702
3	VR Design	0.1642
4	Content Quality	0.1642
5	Assessment	0.1636

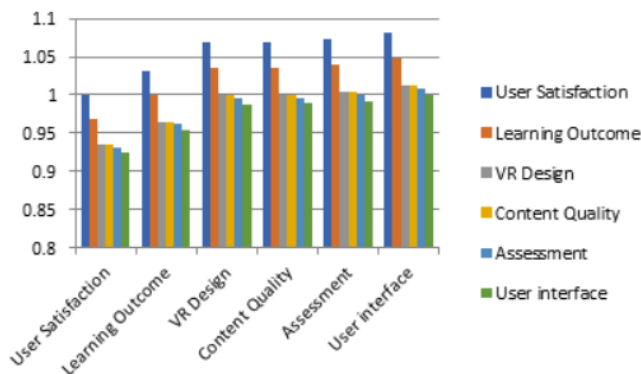


Fig. 23. Normalized value for each criteria

The results indicate that User Satisfaction (17.56%) is considered the most influential factor in the evaluation of 3D learning environments. This is closely followed by Learning Outcome (17.02%), reinforcing the dual focus on experience and educational impact. These findings align with research in digital learning that emphasizes the importance of both emotional engagement and cognitive gain.

VR Design, Content Quality, and Assessment follow in the next tier of importance, all within a narrow range (~16.3–16.4%). The relatively small differences in weights suggest that while User Satisfaction is a leading factor, all five criteria are regarded as necessary components of an effective 3D educational experience.

The AHP results support a balanced design strategy where both technical and instructional elements are equally prioritized. Specifically, developers of 3D educational tools should ensure:

- Engaging and satisfying user experiences;
- Tangible learning outcomes;
- Visually coherent and interactive design;
- High-quality instructional content; and
- Effective evaluation and assessment mechanisms.

The closeness of the weights also implies a high level of judgment consistency among evaluators, although this should ideally be confirmed through a Consistency Ratio (CR) check for validation.

B. Normalized Matrix Analysis for 3D-Based Content

Table 2 presents the normalized pairwise comparison matrix derived from the Analytic Hierarchy Process (AHP) analysis applied to the 3D-based educational content. The matrix was generated by dividing each entry in the original comparison matrix by the sum of its corresponding column, allowing for standardized comparisons across all criteria.

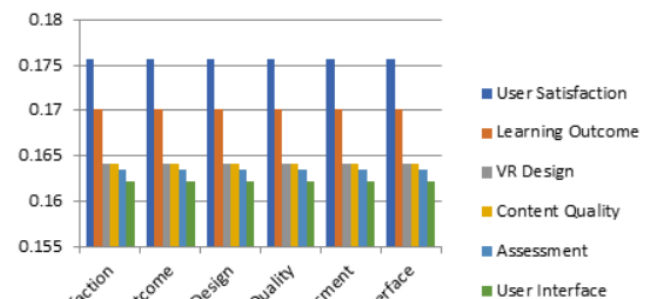


Fig. 24. Normalized Matrix

The normalized matrix provides insights into the consistency and judgment patterns of evaluators. The matrix values are nearly identical across all columns and rows, indicating strong agreement among expert evaluators and a high degree of internal consistency.

The highest values consistently appear for User Satisfaction (0.1756), while the lowest are associated with Assessment (0.1636). The other criteria fall in a narrow range between these values, suggesting that no single criterion dominates the evaluation framework, but rather, all are perceived as important.

These findings underscore a balanced evaluation structure in which all aspects of the 3D learning experience—technical, pedagogical, and experiential—are considered essential. However, the slightly higher weighting for User Satisfaction implies that learners place a strong emphasis on usability, engagement, and comfort within digital learning systems.

The structure of the normalized matrix also supports the validity of the resulting priority vector, which is derived as the row average of this matrix. This vector guides

instructional designers and developers in prioritizing improvements to 3D learning systems based on weighted decision-making.

1) *Purpose of the Analysis:* This study aimed to evaluate the effectiveness of 360° and 3D web-based educational content using the Analytic Hierarchy Process (AHP). The goal was to identify which instructional design elements most influence user perceptions of learning quality, based on quantitative feedback from participants.

2) *Criteria Considered in the Evaluation:* The AHP model included six core evaluation criteria, each reflecting a key dimension of instructional quality in immersive web content:

- a) *Content Quality*
- b) *VR Design*
- c) *User Interface*
- d) *Assessment*
- e) *Learning Outcome*
- f) *User Satisfaction*

These criteria were selected based on their relevance to digital learning environments and were evaluated through user surveys using a 10-point rating scale.

3) *Results of AHP Weight Analysis:* The priority weights derived from the normalized AHP matrix are presented in Table 6, highlighting the relative importance of each criterion.

TABLE VI. AHP MATRIX

№	Criteria	Weight(%)
1	User Satisfaction	17.6%
2	Learning Outcome	17.0%
3	VR Design	16.4%
4	Content Quality	16.4%
5	Assessment	16.4%
6	User Interface	16.1%

The results show that User Satisfaction received the highest weight (17.6%), identifying it as the most influential factor in users' evaluation of the digital content. This highlights the critical role of learner experience, enjoyment, and usability in determining the success of 3D/360° instructional tools.

Learning Outcome also scored highly (17.0%), reflecting the content's pedagogical effectiveness. VR Design, Content Quality, and Assessment received nearly equal importance (16.4%), while User Interface scored slightly lower (16.1%).

4) *Consistency Evaluation:* To validate the reliability of the pairwise judgments, the AHP consistency indicators were calculated as follows:

TABLE VII. AHP INDICATORS

№	Metric	Value
1	Maximum Eigenvalue ($\lambda_{\max}$)	≈ 6.03

№	Metric	Value
2	Consistency Index (CI)	≈ 0.007
3	Random Index (RI)	1.24
4	Consistency Ratio (CR)	≈ 0.005

Since $CR < 0.1$, the matrix is considered logically consistent, confirming the validity of the users' comparative judgments. This indicates that the evaluation results can be used with confidence in the design and enhancement of immersive learning experiences.

The slight variation in weights across the criteria suggests that learners perceive multiple dimensions of immersive content as equally important. While User Satisfaction emerged as the highest priority, the closeness of weights shows that learning outcomes, design quality, and content structure all contribute significantly to the effectiveness of 360° and 3D web-based learning.

These findings support the development of balanced instructional strategies that simultaneously address technological, pedagogical, and user experience dimensions. For future implementation, developers are encouraged to:

- Emphasize learner satisfaction through intuitive, enjoyable interactions
- Ensure strong learning outcomes through content structure and clarity
- Maintain high standards in visual design and assessment mechanisms

Overall, the AHP findings reinforce the multidimensional value of immersive web content in education and provide a reliable foundation for continuous improvement and adoption in blended or online learning environments.

To support the enhancement of 3D and 360° digital content as well as Virtual Reality (VR) simulation development, a series of user surveys were conducted. Selected results from these surveys have been presented in the previous section, highlighting key insights for ongoing improvements. Based on the findings, continuous refinement and iterative development of the VR learning modules are actively underway.

Furthermore, recent advancements have enabled the integration of hand tracking technology, allowing users to interact with virtual objects directly through gestures without the use of physical controllers. This method significantly enhances the sense of immersion and realism within the VR environment by enabling more natural and intuitive user interaction.

VI. CONCLUSION

Digital learning resources, including multimedia content and virtual laboratories, offer numerous pedagogical advantages such as flexibility in time and space, cost-effectiveness, accessibility, and increased opportunities for self-directed learning. The development of immersive virtual simulations and electronic learning content is a multidisciplinary process, requiring the integration of technological advancements, pedagogical frameworks, and digital innovation.

In this study, we developed a fully immersive Virtual Reality (VR) educational content module, which represents a novel contribution by incorporating the latest developments in immersive media. The work was guided by recent advancements in WebVR, 3D visualization, VR and AR technologies, and aligns with future trends such as 5G-enabled education, virtual field trips, and interactive simulation-based training.

While immersive 3D and VR-based educational systems hold tremendous promise, they also demand substantial investment in time, hardware, software, and skilled personnel. However, recent reductions in the global market price of hardware have made such technologies increasingly accessible; for instance, the average cost of a modern VR headset is now approximately \$500. Although core development platforms such as game engines may be available for free (e.g., Unity, Unreal Engine), the process of creating custom 3D objects, simulations, and VR libraries remains both resource- and time-intensive.

Keeping pace with rapid technological evolution, we designed a VR-based digital content prototype using a hybrid approach that integrates 360° panoramic virtual environments, 3D objects, and 3D animation. Notably, this type of web-based immersive educational content is new to Mongolia and is only beginning to gain adoption globally. One of its distinct advantages is cross-platform accessibility: students can explore 3D dental structures in a browser-based environment, independent of the operating system, while also gaining access to a fully immersive VR simulation through game engine-based development.

The interactive prototype is currently hosted at: <http://202.70.34.27:8089/> and is currently viewable on desktop computers only (development is ongoing).

From a pedagogical perspective, our central design principle has been to enrich instructional content and ensure that course objectives are clearly delivered to students. The digital tools developed throughout this project are intended not only to enhance learning outcomes but also to provide a scalable, immersive, and flexible alternative to conventional laboratory environments.

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