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Design and Research of Procedural XR Educational Content Based on Hand Tracking

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[Abstract]

This study proposes a development approach for immersive instructional content that maximizes educational effectiveness by combining the principles of process-based learning with XR (eXtended Reality) technology. While demand for immersive content is increasing in industrial and educational settings to efficiently learn complex equipment and work procedures, research incorporating systematic process design and user experience (UX) remains limited. This study presents an XR-based procedural teaching material design framework and discusses the content development process and expected educational effects using this framework. Specifically, it proposes a development approach centered on task procedure analysis, UX-based interaction design, and real-time feedback provision during the research planning stage. Future experiments aim to validate the potential for improving learning efficiency, procedural execution accuracy, and immersion. This study demonstrates the practical applicability of a procedure-centered XR education model and can contribute to innovation in training across various industrial settings.

▸ **Key words**: XR, Procedure-based learning, NUI, Immersive Learning, Experiential learning

[요 약]

본 연구는 절차 기반 학습의 원리와 확장현실(XR) 기술을 결합하여 교육 효과를 극대화하는 몰입형 교육 콘텐츠의 개발 접근법을 제안한다. 산업 및 교육 현장에서 복잡한 장비와 작업 절차를 효율적으로 학습하기 위해 몰입형 콘텐츠에 대한 수요가 증가하고 있지만, 체계적인 프로세스 설계와 사용자 경험(UX)을 접목한 연구는 제한적인 실정이다. 본 연구에서는 XR 기반의 절차적 교재 설계 프레임워크를 제시하고, 이를 활용한 콘텐츠 개발 과정과 기대되는 교육 효과에 대해 논의한다. 연구 기획 단계에서 과제 절차 분석, UX 기반 인터랙션 설계, 실시간 피드백 제공을 중심으로 한 개발 접근 방식을 제안한다. 향후 실험을 통해 학습 효율성, 절차 수행 정확도, 몰입도 향상 가능성을 검증할 예정이다. 이 연구는 절차 중심 XR 교육 모델의 실제 적용 가능성을 입증하고 다양한 산업 현장의 교육 혁신에 기여할 수 있을 것으로 기대한다.

▸ **주제어**: XR, 절차기반학습, NUI, 실감형 교육, 체험형 학습

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I. Introduction

1. Introduction

1.1 Research Background

Learning in industrial and educational settings increasingly demands the ability to accurately and safely perform complex work procedures. Traditional document-based manuals or video materials struggle to engage learners and often lack alignment with actual procedures. While recent advances in extended reality (XR) technology enable immersive learning environments, research integrating procedural learning theory into XR settings remains limited.[3]

1.2 Need for Research

1) Ensuring Safety: Preventing errors in complex and hazardous work environments

2) Procedure Learning Efficiency: Enhancing task comprehension and execution accuracy through step-by-step real-time feedback

3) Lack of Systematic Design Guidelines: Insufficient guidelines integrating procedure analysis and UX during XR content design

1.3 Research Objective

The ultimate goal of this study is to apply procedural learning theory to XR (eXtended Reality) technology, thereby establishing the foundational structure for a modular immersive education solution.[3] Specifically, we aim to design a universal XR educational content framework that is not limited to specific industries or equipment, but can be extended to diverse educational procedures and teaching materials.

II. Preliminaries

1 Related works

1.1 Trends in XR-Based Educational Technologies

Recent XR (eXtended Reality) technology is expanding into immersive educational environments encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR). Azuma (1997) defined the concept of augmented reality, proposing that overlaying virtual objects onto real-world spaces enhances learner immersion and interaction.[1]

Milgram & Kishino (1994) proposed the Reality-Virtuality Continuum, theoretically establishing the educational potential of XR technology.[2]

In the education field, these XR technologies are widely utilized in industrial, military, medical, and engineering education due to their advantage of visually simulating complex procedural tasks.

For example, Lee & Kim (2020) reported that VR-based training significantly improved learners' procedural accuracy in industrial safety education, while Chung & Park (2021) revealed that user immersion and interaction directly impact learning efficiency from a UX design perspective.[6][7]

Domestically, Kim et al. (2022) also demonstrated that developing virtual reality-based equipment inspection content reduces the cognitive load of procedural learning and enhances learner immersion.[5][10]

While these studies show that XR technology contributes to improving learners' spatial understanding and practical training efficiency, most research is limited to specific equipment or single training scenarios. There is a lack of cases where it has been expanded into a universally applicable modular procedural training system.[14]

1.2 Global XR Market Size and Education Market Size

The global extended reality (XR: VR + AR + MR) market size is projected to grow to approximately $253.5 billion by 2032, with a compound annual growth rate (CAGR) of about 30.4%. According to a KPMG report, the XR industry is rapidly expanding across its entire value chain, with high growth potential in the content, platform, and device sectors. South Korea currently holds a market share of approximately 2.6% in the global XR market, with significant growth potential noted in AR/VR hardware and software technologies.

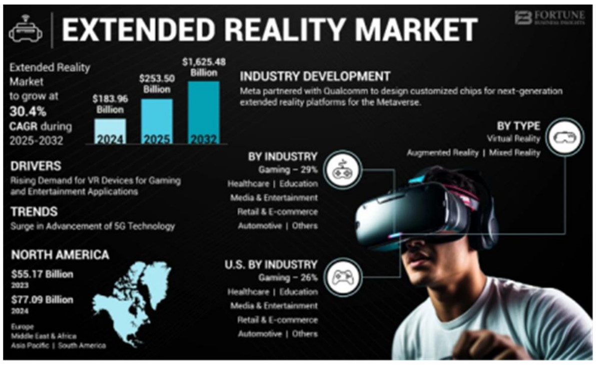

Fig. 1. Extended Reality Market

The global AR/VR education market size was approximately USD 10.8 billion in 2023 and is projected to grow to USD 55.31 billion by 2032. The CAGR is presented as approximately 19.9%. Another report evaluates the AR/VR education market at approximately USD 20,102.25 million in 2024, projecting growth to USD 67,743.63 million by 2032, with a CAGR of approximately 16.4%.

The South Korean AR market is projected to reach approximately USD 3,385.6 million in revenue by 2024 and grow to USD 26,890.1 million by 2030, with a CAGR of about 40.2% from 2025 to 2030. Demand for AR/VR specialized in the education/training sector is expanding rapidly, particularly driven by the transition to smart classrooms and policies strengthening digital education.

1.3 Research on XR Teaching Materials and Modular Education Solutions

Recent studies have attempted to evolve beyond single XR content toward a Modular XR Training System.[14]

Park et al. (2022) proposed a modular structure for aircraft maintenance training XR content, enabling the combination of procedure-specific learning units.[8] Shin & Lee (2023) demonstrated that reusing common procedure modules in medical simulation training can simultaneously improve development costs and learning transfer effects.[9]

Similarly, domestic XR education research is actively developing immersive procedural learning centered around teaching aids.

For example, in the defense sector, XR-based instructional material systems are being introduced for equipment inspection and weapons system maintenance training. In education, attempts to implement hands-on curriculum content using XR are increasing to enhance student immersion and procedural understanding. However, existing research has primarily focused on developing content optimized for specific industries, and a theoretical framework for a modular XR procedural learning platform reusable across diverse domains has yet to be established.

This study aims to present a foundational model for a universal, scalable, modular XR education solution by combining procedural learning theory with storyboard-based UX design techniques to address these limitations.[3][5]

III. The Proposed Scheme

1. Research Methodology

1.1 Workflow Analysis

To provide training on the use of teaching aids employed in education or practical training, we will develop immersive XR content based on procedure-based scenarios. To achieve this, we will model the actual teaching aids and structure the necessary content for each use case, developing step-by-step XR training content as follows.

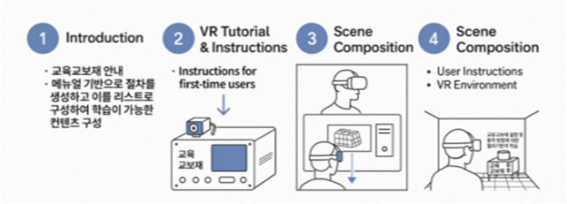

Fig. 2. XR Teaching Materials Immersive Education Framework Diagram

1) Field Procedure Analysis for Teaching Materials

Task Flow Analysis (TFA) and risk factor identification (FTA/FMEA) techniques are applied to break down complex procedures performed in industrial and educational settings into step-by-step segments.[4] For each step, the task objectives, input/output states, tool and equipment requirements, and potential error points are defined. Actual performance contexts are captured through expert interviews and field observations and incorporated into the educational content.

2) Storyboard-Based User Step-by-Step Guidance Design

Instead of designing simple UX screen flows, we visually design the learner's action-feedback-outcome flow using storyboard techniques. This allows learners to sequentially and immersively experience actual work procedures, while facilitating collaboration among instructional designers, developers, and field experts during the design process.

1.2 Research and development

Implement a 3D interactive environment based on storyboards using the Unity engine. 3D modeling is created using software like Max and Blender to closely resemble actual equipment and work environments. Each stage incorporates visual highlighting, real-time status feedback, and error detection and guidance features. It is designed to record user behavior history, enabling feedback based on learning data. Based on this, we developed XR educational content as follows.

1) Develop scenario-based procedures enabling step-by-step practice

XR teaching material content is structured with separate scenarios, allowing step-by-step practice following the scenario. These steps are displayed as a list, and users progress through each item one by one, with completed and incomplete steps clearly distinguished.

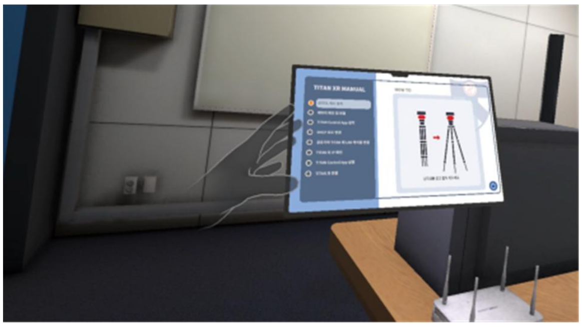

Fig. 3. Training List (Tablet)

The image above and the tablet object were implemented to describe the training list and the training content for each list. The training content is organized step-by-step on the left side to be viewable as a list. For each step, the detailed training content is described on the right side when that step is being taught.

Fig. 4. Training Completion & Non-Completion Indicator

The left education list is designed to allow real-time tracking of currently ongoing training, completed training, and remaining training.

Each step is color-coded to distinguish completed tasks from those in progress, allowing you to track the progress of the training.

2) Develop text and guides detailing actions required for each procedure

Develop guides that provide written instructions and voice data converted from the text for each action required in the scenario's procedures, enabling learning about the training process.

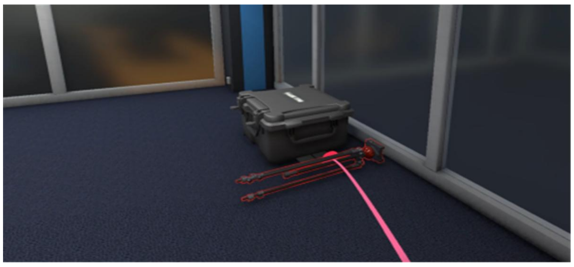

Fig. 5. Guide markings for movement

When you need to move for the corresponding training, place your finger on the location you should move to, and a guide line for movement will appear.

Provides an outline of the object the learner should take as the next action, offering a hint for the action.

Fig. 6. Object Guie Outline

As shown in the image above, an outline is provided around the object to be practiced, indicating that it is the item to be taught this time, and through this, education is conducted via interaction.

3) Development of a History function enabling continuous training by retaining learned content.

We developed a feature to store the last completed learning step locally, allowing subsequent training sessions to resume from the point immediately following the final completed step.

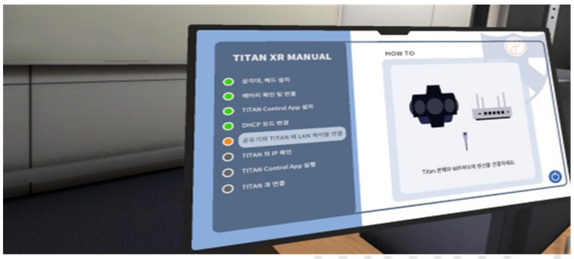

Fig. 7. Education History Feature

As shown in the figure above, you can monitor the progress of training programs in real time. You can check which training courses you have completed and which ones remain out of all practical training courses.

The History feature enables education starting from the next step after the student's education has concluded.

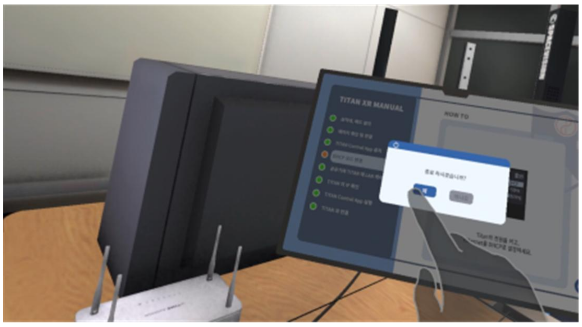

Fig. 8. Education History Feature2

As shown in the figure above, the training program completed up to that point is saved when the training session ends. Subsequently, when proceeding with the practical training, the training can be continued from that stage onwards.

4) Development of motion recognition functionality to enable immersive learning.

We developed hand-tracking-based motion recognition to enable learning without a separate controller, facilitating highly realistic training.[12]

Developed functionality enabling left/right movement and teleportation by configuring a specific motion (thumb motion).

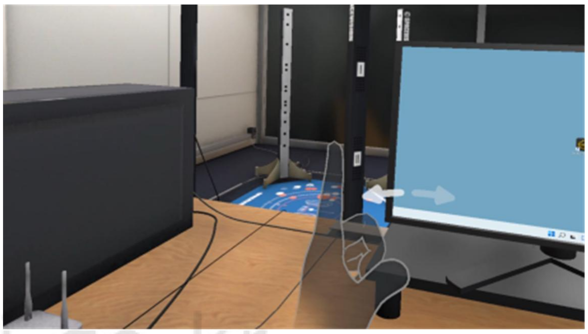

Fig. 9. Motion detection function (rotation)

Fig. 9 shows motion recognition supporting rotation. When you raise your thumb, arrow UI for left and right rotation appears. Performing a motion to grasp each arrow with your thumb and index finger rotates the object left or right.

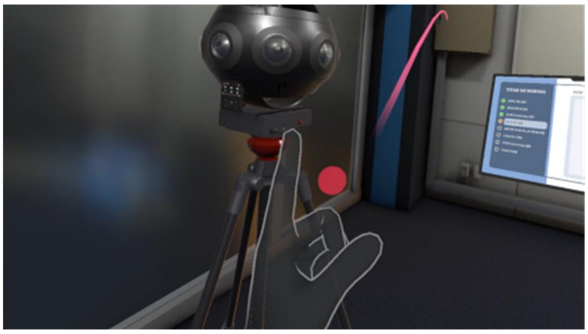

Fig. 10. Motion detection feature (movement)

Fig. 10 shows motion recognition that supports movement. When you raise your thumb and point to the destination, a guidance UI appears for the location. After that, clicking the final destination with your thumb moves you to that point.

IV. Conclusions

1. Final Results

The ultimate outcome of this research is the establishment of a modular educational solution framework integrating procedural learning theory with XR technology. The storyboard-based procedural design model, step-by-step user guidance interactions, and real-time feedback structure developed during the research serve as a standardized structuring model for XR educational content that is reusable across diverse industrial and educational environments.

1.1 Proposal of a Procedure-Based XR Teaching Material Design Framework

A storyboard-based content development methodology combining procedural analysis and UX design is presented. By defining feedback and interaction structures for each learning stage, it supports learners' immersive procedural learning.

1.2 Development of a Modular XR Educational Content Structure

Break down educational procedures into 'module units' to implement a structure enabling content reuse and combination, thereby establishing a universal framework that can be flexibly applied to industry-specific and job-specific procedural learning.

1.3 Implementation of an XR-based immersive learning prototype

Develop experimental content simulating actual teaching material procedures within a Unity-based XR environment, and establish an empirical foundation by validating the operation of the user interface (UI) and feedback system.

2. Utilization Plans

This study enables diverse applications through the modular structure of XR educational content and design based on procedural analysis.

First, educational procedures can be subdivided into modules, enabling a structure where content can be reused and combined. This allows for the independent development of common learning units that are not limited to specific equipment or procedures, and can be combined as needed.

For example, when the operating procedure for a specific piece of equipment consists of A>B>C, even if the procedure for another piece of equipment consists of A>D>E, the common procedure module ‘A’ can be reused.

Second, this framework can be applied to all fields requiring procedural learning (industry, military, healthcare, etc.). All industrial sectors conduct procedure-focused training programs, and it can be utilized as XR content for safety training in high-risk industries (manufacturing, energy, aviation, defense).

The results of this study can be applied to procedure-centered training programs across various fields such as education, industry, military, and healthcare. Specifically, the following concrete application methods can be proposed.

2.1 Industrial Site and Safety Training Application

Used as XR content for safety training in high-risk sectors such as manufacturing, energy, aviation, and defense. Reduces accident risks and improves training efficiency by mastering procedures before operating actual equipment.

Fig. 11. Job Training and Safety Education Using XR[18]

2.2 Commercialization of Educational XR Content

Development of XR teaching materials applicable in universities, vocational schools, and public institutions enables scalability, maximizing learning effectiveness by providing an immersive experience similar to using physical teaching materials.

Fig. 12. XR in the Classroom[18]

2.3 Foundation for Building a Modular XR Education Platform

The system developed in this study enables the establishment of a sophisticated learning data collection framework.[17] It records user behavior history and enables feedback based on learning data (hand movements, gaze, procedure execution time, error occurrence points during learning). Through this real-time feedback data in procedure-based learning, it is possible to identify the fundamental cause of why errors occurred, going beyond simple correct/incorrect answers, and provide sophisticated data-based diagnosis and feedback.

Additionally, through a structure subdivided into 'module units,' it can recommend customized learning paths that identify strengths and weaknesses at each stage based on the learner's learning history, enabling selective learning of specific procedures for addressing weaknesses.[15]

Based on the procedural modules and learning management structure developed in this research, it can evolve into an integrated XR learning platform that combines AI-based personalized learning recommendations and data feedback capabilities.[16]

2.4 Industry-Academic Collaboration and Public Project Linkage

Contributing to the establishment of a field-centered immersive job training model by applying XR educational content to collaborative projects with public institutions, the military, and industrial entities.

3. Expected Effects

The outcomes of this study provide the following expected benefits in technical, educational, and industrial aspects.

Fig. 13. Various Anticipated Benefits Using XR[18]

3.1 Educational aspects

Establishing a feedback loop structure that enhances learning efficiency and immersion by introducing real-time feedback mechanisms from procedure-based learning into XR environments[11], enabling immediate correction of learners' misconceptions and erroneous actions. Effect of reducing cognitive load for complex task procedures.

3.2 Technical aspects

By structuring XR-based procedural learning, we present a modular XR content standardization model and establish an integrated development process for UX, content, and learning data through storyboard-based design.[14][13]

We lay the foundation for a data-linked XR learning architecture to enable AI analysis and utilization of learner behavior data.[17]

3.3 Industrial aspect

Establish a cost-effective XR development model that reduces duplication in educational content production and can be expanded across diverse industries. Visualize practical procedures in industrial settings to evolve into a field-centric immersive training system. Strengthen the competitiveness of Korea's XR education industry based on a standardized development framework for XR teaching materials.

This study validated the educational applicability of XR technology based on procedural learning theory and presented core foundational technologies for next-generation XR education solutions by structuring them in a modular form.

The framework of this study is expected to evolve into a core component of smart learning environments by combining industry-specific customized content development with AI feedback functionality.

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