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VR IGLOO™: A VR-Based Teaching-Learning Model for Distance Education

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Abstract: Traditional distance learning has been widely adopted for its capacity to provide educational access to a broad and diverse audience, overcoming spatial and temporal limitations. However, it needs to deliver the same immersion and learning effectiveness as face-to-face instruction, particularly in courses requiring hands-on practice, where these limitations become more pronounced. To address this, virtual reality (VR)-based distance learning has gained attention as a potential solution. Previous studies have confirmed that VR-enhanced distance learning can improve educational outcomes; however, a standardized teaching-learning model designed explicitly for VR-based distance learning has yet to be established. Consequently, instructors have often relied on conventional models, leading to variability in instructional quality. This paper proposes the VR IGLOO model, a structured VR-based teaching-learning framework tailored for distance education. For this purpose, analysis of the conventional studies and focus group interview (FGI) of the expert group were conducted. And the validity of the proposed model was verified through Delphi validation.

Index Terms: Virtual Reality, Distance Education, Teaching-Learning Model, Education Model

1. Introduction

Distance education has expanded steadily in response to demand within the education sector, as it offers advantages like broader access and reduced costs. However, traditional distance education has been limited to delivering pre-recorded videos or flash materials online, primarily as an auxiliary tool to face-to-face (hereafter FF) learning. With the onset of the COVID-19 pandemic, there was an increased need to replace FF learning with fully remote alternatives [1, 2]. Many FF learning activities transitioned to distance formats, resulting in various issues. Particularly in practice-intensive curricula or training programs, limitations became evident. Conventional distance education struggled to replicate the presence, immersion, and interactive efficiency of FF learning.

To address these issues, integrating virtual reality (VR) into distance education has garnered attention [3-5]. Numerous studies have demonstrated that VR-based education can enhance learning outcomes [6, 7], and VR-based content is increasingly available in various forms [3-5]. However, a structured teaching-learning model specifically for VR-based distance education has yet to be established.

In this study, we develop a teaching-learning model for VR-based distance education (hereafter VR-based model) to resolve such unevenness in education quality according to each instructor. The development process of the VR-based model is as follows. First, a VR-based model is developed through literature review and focused group interview (FGI). Second, the validity of the VR-based model developed is verified through Delphi verification.

The structure of this study is as follows. Chapter 2 introduces the theoretical background of this study. Chapter 3 defines the research method used to develop the VR-based model. Chapter 4 describes the research results of the VR-based model. Finally, Chapter 5 presents the conclusion and further research tasks.

2. Background

2.1. Virtual Reality

VR enables users to experience reality within an artificial, virtual environment. Implemented through advanced technologies like computers, VR offers several key characteristics that enhance its effectiveness in educational settings [8, 9]. First, VR allows the reproduction of otherwise impossible experiences in real life. For example, while exploring the Earth's core or entering a patient's body in reality is impractical, VR makes such explorations feasible, providing valuable educational material. Second, VR allows flexible manipulation of objects and scenarios. For instance, while altering the size or mass of planets in the solar system is unfeasible in reality, it becomes possible in VR. Additionally, VR can adjust details like wound thickness or blood vessel dimensions as needed, enhancing educational versatility through manipulation. Third, VR enables repeated practice by resetting environments to their original states. For instance, perfecting skills with tools, like a welding instrument, requires extensive practice. VR allows consistent access to a controlled learning environment where repetition can lead to proficiency. Fourth, VR simulates contexts and situations resembling real-world experiences. There are various games based on virtual reality and among such games, there are games that imitate the real world [10-13]. In these virtual reality-based games, various members identical to those in the real world exist and users can interact with them. VR can provide educators with a sense of realism as if they were experiencing it in the real world.

2.2. Related Works

As aimed in this study, in order to develop a VR-based model for distance education for vocational skill development, it is necessary to understand the overall structure by analyzing the teaching-learning model used previously. Tab. 1 below shows examples of the main teaching-learning models used previously.

Table 1. Conventional teaching-learning model

Model	① Pre-design of class	② Pre-learning	③ Checking readiness for class	④ Presenting problems	⑤ Solving problems	⑥ Applying the results	⑦ Feedback
[14]				●	●		●
[15]	●	●	●	●	●		●
[16]		●	●	●	●		●
[17]				●	●		●
[18]				●	●		●
[19]				●	●		●
[20]				●	●		●
[21]				●	●		●
[22]				●	●		●
[23] UMC				●	●	●	●
[23] DDC				●	●	●	●
[23] DCC				●	●	●	●

Most of the cases investigated in Tab. 1 were models for FF learning only, or models for combined forms of FF learning and distance education. However, as the focus of this study is to develop a teaching-learning model specifically for VR-based distance learning, it is necessary to analyze models designed exclusively for distance learning. The additionally investigated teaching-learning model case for distance education based on [24] is shown in Tab. 2 below.

Table 2. Conventional teaching-learning model for distance education

Model.	① Pre-design of class	② Pre-learning	③ Checking readiness for class	④ Presenting problems	⑤ Solving problems	⑥ Applying the results	⑦ Feedback
e-lecture				●	●		●
e-PBL				●	●		●
game and simulation				●	●	●	●
e-case-based learning				●	●		●
Virtual field trip				●	●	●	●
e-project learning				●	●		●
e-goal-based scenario				●	●		●
Guided e-inquiry				●	●	●	●

As a result of the analysis of the teaching-learning model through Tab. 1-Tab. 2, three processes to be considered in this study were defined as follows.

First, it is a preparatory process for education. As a result of the analysis in Tab. 1-Tab. 2, the teaching-learning model for distance education was found to not include the three steps of '① pre-design of class', '② pre-learning', and '③ checking readiness for class', which correspond to the pre-preparation process for education. If the pre-preparation process for education is included, the instructor can check the learner's readiness for class and the learner can quickly adapt to the educational content [15, 16]. Considering these advantages, in this study, it was determined that it is necessary to develop a teaching-learning model including three steps that were not included in the conventional teaching-learning model for distance education. Second, it is a learning process that provides various forms of learning. As a result of reviewing the 8 cases analyzed in Tab. 2, 4 models were identified as the teaching-learning model suitable for the practice-oriented learning, which is the subject of the present study. However, it is found that each model can only provide a specific type of learning as follows:

1) game simulation: iterative learning
2) e-Case-Based learning and e-Goal-Based Scenario: procedure-oriented learning
3) Virtual field trip: simple viewing-type learning

Considering that the demand for distance education is gradually expanding into various fields, the results of this study need to provide various types of education in a combined way. Therefore, in this study, it is determined that it is necessary to develop a teaching-learning model that can provide various types of education such as iterative learning, procedure-oriented learning, and simple viewing-type learning by utilizing the characteristics of VR that can provide various environments.

Third, it is a process of familiarization with the educational environment. As a result of the analysis of Tab. 1-Tab. 2, there was no case in which the familiarization process for the educational environment was considered in terms of the teaching-learning model. It was assumed that this was because, in the cases of Tab. 1 – Tab. 2, learners did not need to adapt to the educational environment additionally because FF learning were conducted or because the platform of classes was a PC even if it was a non-face-to-face (hereafter NFF) class. In the case of the VR-based model for distance education, the resulting product of this study, with the use of VR, a very different educational environment would be provided to learners. An unfamiliar educational environment may reduce the effectiveness of learning for learners. Moreover, in the case of an educational environment to which VR technology is applied, it is very difficult for learners who have not experienced VR technology to adapt themselves. Therefore, it is necessary to introduce a standardized process so that learners can adapt to the educational environment. Considering this point, in this study, it was determined that it was necessary to develop a VR-based model with introduction of the familiarization process so that learners could quickly adapt to the educational environment.

3. Methods

This study utilized a two-step research methodology to develop a VR-based model. First, a focus group interview (FGI) [25] was conducted to evaluate the components of the VR-based model derived through literature review and VR application planning. The FGI was structured into two groups to gather insights from both vocational training experts and industry professionals: Group 1 included higher education and vocational skill development experts. At the same time, Group 2 consisted of professionals in engineering-related industries.

Group 1 focused on exploring factors and operational methods for VR-based distance education. Expert selection criteria included: 1) professional experience with teaching-learning models and 2) expertise in VR. This group comprised three engineering professors, one education professor, and two educational design experts.

Group 2 focused on exploring the practical skills needed in industry fields and how to achieve them in VR-based distance education. Criteria for this group included: 1) employment in engineering, 2) a doctoral degree or higher in engineering, and 3) knowledge of VR. This group comprised eight industry experts. The group of experts recruited for the FGI is shown in Tab. 3. The FGI addressed eight key areas: educational content, feedback methods, evaluation methods, learning environment, learning enhancement, practice improvement, interaction, and VR-specific features. FGI analysis followed Kruger's procedure [25], leading to a draft VR-based model based on the findings.

Table 3. FGI expert group

Group	Occupation	Fields
Higher education specialists and vocational skills development specialists	Professor	Chemical engineering
	Professor	Virtual reality
	Professor	Information and communication engineering
	Professor	Human resource development
	Teaching staff	Vocational skills development, human resource development
	Teaching staff	Vocational skills development, educational technology
Training program stakeholders and industry experts	President	Smart factory
	Senior manager	Construction
	Manager	Software
	President	Industry 4.0
	Vice president	Semiconductor
	Senior manager	Smart factory
	President	Electrical and electronic
	President	Information technology

Second, the content validity and face validity using the test tool were verified by the expert group to verify the validity of the draft VR-based model derived through FGI. As shown in Tab. 5, the expert group included a total of 17 subjects consisting of 6 university professors, 2 university faculties, 2 high school teachers, 1 vocational training instructor at the training center, 4 university education program operators, and 2 government department education program operators. The validity test consisted of six items: validity, relevance, comprehension, universality, utility, and differentiation [26, 27]. For content validity verification, the content validity ratio (CVR) obtained by quantifying consensus was calculated. The Delphi validation method is shown in Tab. 4. Based on the results of Delphi verification, by modifying the draft VR-based model derived through FGI, the development of the VR-based model was finally completed.

Table 4. Delphi verification

Category		Details
Experts		- Education faculty (professors) - Educational and training curriculum operation decision-makers - Government officials (e.g., educational experts) - Educational technology design experts - Technical vocational training experts (vocational training instructors)
Purpose		Verification of the suitability of the model derived through the FGI by experts
Procedure	Questionnaire design	Designing a questionnaire to assess the suitability of the model based on the FGI results
	Delphi survey	Objective responses: 5-point Likert scale for assessing appropriateness Subjective responses: Free-form feedback for model revisions
	Result analysis	CVR calculation Refine the model considering the CVR and survey responses

Table 5. Delphi expert group

No.	Position	Organization	No.	Position	Organization
1	Teaching staff	University	10	Vocational training instructors	Training center
2	Teaching staff	University	11	Professor	University
2	Professor	University	12	Administrator	University
3	Professor	University	13	Administrator	University
4	Professor	University	14	Administrator	University
5	Professor	University	15	Administrator	University
6	Professor	University	16	Administrator	Government
7	Teacher	High school	17	Administrator	Government
8	Teacher	High school		-	

4. Results

4.1. Development of teaching-learning model for distance education based on VR: VR IGLOO

As a result of FGI, opinions as shown in Tab. 6 were expressed.

Table 6. FGI results

Subject	Opinion
Educational content	Guidelines for creating VR contents that are used in actual education are required.
Feedback methods	Methods for multiple learning members to share learning results and solve problems together are required.
Assessment methods	Appropriate assessment criteria for VR practice are required.
Educational environment	Consideration should be given to the existence of differences in the environment between learners (VR devices are widespread, universal devices are used, etc.). Consideration should be given to the dizziness and motion sickness caused by VR devices (steps to adapt to VR devices, perform several times in a short time, etc.). Consideration should be given to the hardware to be used in VR-based non-face-to-face education (should not be limited to a specific hardware or platform).
Improving learning effect	Methods to maximize the advantage that learners can repeat learning on their own are required.
Improving practice effect	Step-by-step assessment methods for improving the learner's concentration on practice are required.
Interaction	Consideration should be given to the interaction methods and equipment to provide immersion.
VR property	It is required to review whether the practice in VR can replace the actual equipment. When VR is applied, there must be a different practical content from the conventional ones (e.g., coding can be applied to VR). Consideration should be given to the fields of education and training where VR can be effectively applied. Because the scope of VR application is wide, the results may be ambiguous, so it would be better to develop a narrower application range of the teaching-learning model.

The draft VR-based model developed based on the three main research directions derived from the literature review and the FGI results are shown in Fig. 1 below.

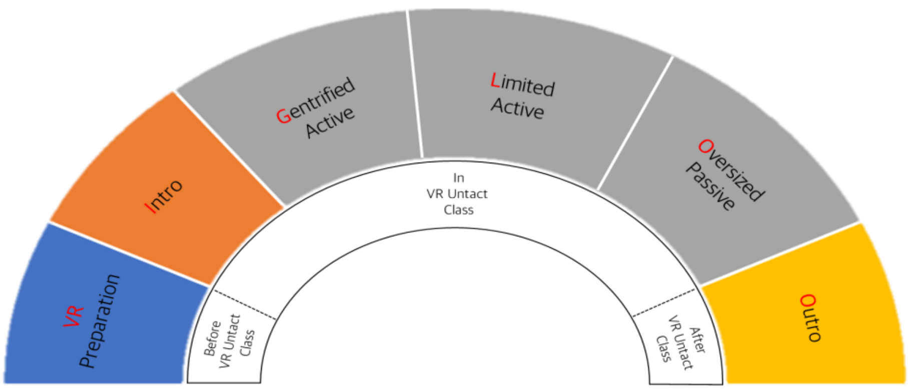

Fig. 1. Draft of VR-based teaching-learning model

The VR-based model is largely divided into 'Before VR Untact Class', 'In VR Untact Class' and 'After VR Untact Class' and the actual VR-based NFF class was divided into 3 types ('Gentrified Active', 'Limited Active', 'Oversized Passive') according to the function, class content, and VR technology used. A validation process was required in order for the draft VR-based model presented in Fig. 1 to be recognized. For this purpose, the model developed through the Delphi verification process was supplemented. The validation results are shown in Tab. 7 below.

Table 7. Delphi verification results

No.	Item	Question	Average	Standard Deviation	CVR
1	Validity	Are the step names of the presented model properly written?	4.47	0.799	0.882
2	Relevance	Are the step-by-step descriptions of the model presented adequately?	4.529	0.799	0.882
3	Understanding	Is the presented model written in a way that is easy to understand?	4.411	0.618	0.882
4	Catholicity	Can the presented model be applied irrespective of the educational target and educational field?	3.47	1.124	0.176
5	Usability	Can the presented model be usefully applied to actual VR-based non-face-to-face training?	4.294	0.771	0.647
6	Differentiation	Is the presented model (for VR-based non-face-to-face education) different from conventional models?	4.294	0.685	0.764

As a result of the Delphi verification, the CVR values in the five fields of validity, relevance, comprehension, utility, and differentiation were found to be 0.647~0.882. In general, in Delphi verification, if the CVR for 15 people is 0.49 or more or the CVR for 20 people is 0.42 or more, it can be judged that the item has validity. The Delphi verification of this study was performed on 17 people, so if the CVR was 0.42 to 0.49 or higher, it could be judged that the item was valid [26]. In the present Delphi verification, five fields of validity, relevance, comprehension, utility, and differentiation showed values that far exceeded the corresponding values, and thus, the validity of the proposed VR-based model draft based on the FGI results was confirmed. In the result of this Delphi verification, question 4, which is a question about universality, showed relatively low mean and CVR values compared to questions about other fields. This was thought to be because this VR-based model was developed focusing on 'practice-oriented learning'.

In order to develop a better VR-based model, detailed opinions from experts are required in addition to the CVR value of the model. For the purpose of collecting these opinions, items that allow experts to freely write opinions about the parts that need correction in the draft VR-based model along with the Delphi verification were added to the questionnaire. The results were largely summarized into four opinions as follows.

First, it was suggested that it would be helpful in understanding the model if additional explanations are added so that the meaning of the names of steps used in this model, such as 'Gentrified Active' and 'Oversized Passive', will be clearly revealed. Second, with respect to the field of application, it was suggested that the education target using this VR-based model should be divided, and an application example field in which each step of the proposed model can be used should be added. Third, with respect to the interaction target, it was suggested that it is difficult to understand interactions between which learning members occur at each type, so it is necessary to clearly express the corresponding content. In addition, it was suggested that a feedback method that considers the interaction between instructors and learners should be added. Fourth, it was suggested that examples of applying VR technology to various practice forms, learning materials, and learner participation methods should be added. It has also been suggested that for this purpose, the tool or interaction column needs to be made more specific. Finally, the final draft of the VR-based model, which was modified by considering all the above, is shown in Fig. 2 below.

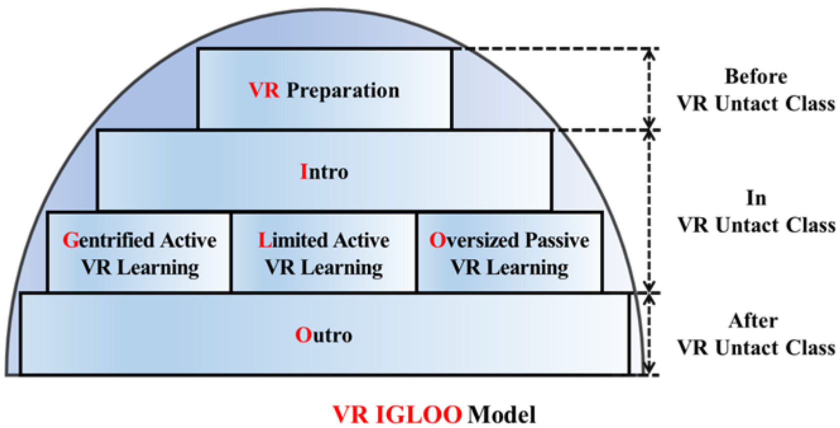

Fig. 2. Final draft of teaching-learning model for VR-based distance education: VR IGLOO model

VR IGLOO, the model name proposed for VR-based distance education, has such a meaning that learners can build up the required knowledge in the training process using VR as if they were building bricks of an igloo.

The goal is to make students obtain their own knowledge for themselves with the proposed model consisting of 4 steps (‘VR Preparation’, ‘Intro’, ‘Gentrified Active VR Learning’, ‘Limited Active VR Learning’, ‘Oversized Passive VR Learning’ , and ‘Outro’)

In the ongoing educational process and training program, type of VR learning (‘Gentrified Active VR Learning’, ‘Limited Active VR Learning’, ‘Oversized Passive VR Learning’) was designed to be exclusively selected according to the goal that learners need to achieve and the content of the class, or by selectively applying two or more types.

The finally proposed VR-based model consists of three components: ‘Before VR Untact Class’, ‘In VR Untact Class’, and ‘After VR Untact Class’.

First, the ‘Before VR Untact Class’ includes the ‘VR Preparation’ step. ‘VR Preparation’ is a step in which the educator analyzes the educational content to make them as VR content, and the learner's environment in order to select appropriate conditions for the VR environment. In addition, as the conventional pre-learning step is incorporated, the instructor will notify the learners of the contents of the pre-learning as needed in the corresponding step. For details on ‘VR Preparation’ step, refer to Appendix A.

Second, the ‘In VR Untact Class’ includes ‘Intro’ and three ‘Case of VR Learning’ steps. First, the ‘Intro’ step is a step in which after VR-based distance education starts, the learner’s current learning environment is checked to make sure that one can take VR-based NFF classes without any problems. The learner’s learning environment is largely divided into the VR environment aspect and the prior knowledge aspect, and is reviewed through the detailed steps of ‘Ready VR Learning’ and ‘Student Check’, respectively. ‘Ready VR Learning’ is the step to check the learner's VR environment and help the learner adapt to the VR environment. Next, ‘Student Check’ is a step that provokes interest and motivation of learners while checking the learner's understanding of prior learning and presenting learning goals. For more information about the ‘Intro’ step, refer to Appendix B and Appendix C.

Next, the ‘Case of VR Learning’ step is a step in which actual VR-based distance education is carried out, and the types are classified according to the nature of the provided VR educational content. The three VR learning types classified according to the level of interaction between VR educational content and learners and the content are as follows: ‘Gentrified Active VR Learning’, ‘Limited Active VR Learning’, and ‘Oversized Passive VR Learning’.

‘Gentrified Active VR Learning’ is a suitable type for content that provides active and diverse interactions between learners and VR educational content. In this type of learning, the learner can directly operate the virtual equipment through various interactions, so that the ability to operate the equipment used in practice can be enhanced without practicing in the field. This type of class can be composed of the following contents: checking the learning contents, providing roles in a virtual story, virtual machine familiarization, providing practice goals, repetition of practice using virtual machine, checking the results and applying the results. For more information about the ‘Gentrified Active VR Learning’ type, refer to Appendix D.

‘Limited Active VR Learning’ is a suitable type for content that provides an active but unified interaction between learners and VR educational content. In this type of learning, the learner deeply enters into a character in the story in the VR educational content, experiences a story flow, and performs a job, thereby learning the overall flow of the job and the contents necessary for each phase. This type of class can be composed of the following contents: checking the learning contents, providing roles in a virtual story, providing assignments in virtual story, performing the assignment and checking the results. For more information about ‘Limited Active VR Learning’ type, refer to the Appendix E.

‘Oversized Passive VR Learning’ is a suitable type for content where there is no interaction between the learner and VR educational content. In this type of learning, theoretical knowledge can be mainly learned through educational contents commonly provided in conventional FF or NFF classes. However, it can be seen as an extension of the conventional learning method in that it enables the acquisition of knowledge through experience using VR technology. This type of class can consist of the following contents: checking the learning contents and watching VR content (video) for learning. For more information about the oversized passive VR learning type, refer to the Appendix F.

Therefore, the three types can be outlined as follows. ‘Gentrified Active VR Learning’ focuses on high levels of learner interaction, allowing participants to freely manipulate and communicate with virtual tools (or environments) and other people to practice skills. In contrast, ‘Limited Active VR Learning’ emphasizes following predefined steps or procedures within the virtual environment, prioritizing an understanding of the overall workflow over detailed manipulation. Lastly, ‘Oversized Passive VR Learning’ is centered on one-way education, focusing on theoretical knowledge rather than practical skills. In this type of learning, virtual objects (or environments) serve as supplementary tools to enhance learners' comprehension.

Third, ‘After VR Untact Class’ includes the ‘Outro’ step. In the outro step, class results can be shared and mutual feedback is possible after VR-based distance education is finished. In accordance with expert advice, assessment items were added as separate detailed steps, the word assessment was used instead of the word formative assessment, and various examples of tools and interaction methods that instructors could choose were added. For details on the outro step, refer to the Appendix G.

Each step of ‘VR Preparation’, ‘Intro’, ‘Gentrified Active VR Learning’, ‘Limited Active VR Learning’, ‘Oversized Passive VR Learning’, and ‘Outro’ described above is described in detail with activities, methods and strategies, tools, and interactions, as shown in Appendix A-G.

4.2. *VR IGLOO model application guide*

The developed model may have its own implication when it is used to design VR-based distance education based on the model and develop new contents accordingly. In this section, a checklist-type proposed model application guide was established to provide guidelines. The established checklist is structured for instructors to simply check according to the characteristics of the class to be carried out. In the checklist shown in Appendix H-K below, the instructor gets to check the activities required for each step and how to provide those activities to the learner. Each of these checked items becomes a component of VR-based distance education content by itself. After documenting the checklist, the final result can be used as a guideline to compose content for VR-based distance education. In other words, when an instructor is going to use the proposed model, one may figure out how to design a class by creating a checklist. In addition, an example of the result using the above checklist for the development of new contents applying the VR IGLOO model is shown in Appendix L.

5. Conclusion

This study developed VR IGLOO, a VR-based model for vocational competency development, through sequential phases of model development and verification. In the model development phase, the conventional VR-based model was first analyzed to establish foundational steps. Following this, FGI sessions were conducted to incorporate expert insights, culminating in a draft model built from both the conventional model analysis and FGI results. In the verification phase, Delphi validation was conducted with an expert group to establish the draft model's validity. Subsequently, the model was finalized by refining the draft based on Delphi's feedback. Additionally, a practical application guide (checklist) was created to assist in classroom implementation. The VR-based model thus offers instructors structured guidelines for VR-based distance education and presents learners with a diverse range of VR-based learning experiences. Moreover, the VR-based model is anticipated to enhance the quality of VR-based distance education by fulfilling four specific roles. First, it provides a framework for analyzing and enhancing existing VR-based educational content. Second, it aids in creating a systematic process for developing new VR-based distance education initiatives. Fourth, it is expected to be able to guarantee learners' right to learn by contributing to the rapid transition from FF learning to VR-based distance education in a situation where FF learning is limited due to global disasters such as the COVID-19 pandemic.

However, while the study proposed a VR-based model, it has some limitations. Firstly, the current proposed model is developed based on the perspective of instructors (experts in education and industry) and does not include the perspective of learners (students). Therefore, it is necessary to supplement the proposed model by conducting interviews with learners. Second, the number of experts involved in the FGI for model development was 14, while 17 experts conducted the model validation, resulting in a relatively small sample size, which limits the generalizability of the findings. Therefore, Future works, we would like to expand the number of experts from different fields and supplement the proposed model with learners' interviews to increase its reliability and applicability. In addition, we would like to conduct a study that deals with and evaluates the practical process of applying the proposed model in actual educational settings.

Appendix A Final version of proposed VR-based teaching-learning model for distance education, Step 1: VR Preparation

Contents	Description	Methods /Strategy	Tool /Interaction	Step of conventional model
Design of class content	Defining VR contents type and method	Distribution of environmental guidelines	- Guideline document - Class material - Video - Textbook	① Pre-design of class ② Pre-learning
Learner environment analysis	Selecting VR contents type and hardware			
Advance notice of class content	Notice on the contents of class Distribution of the learning content material	Performing pre-learning		

Appendix B Final version of proposed VR-based teaching-learning model for distance education, Step 2: Intro (Ready VR Learning)

Contents	Description	Methods	Tool /Interaction	Step of conventional model
Checking learner environment	Checking VR environment	Providing question-and-answer window for emergencies Monitoring to confirm the environment	Provided based on 'Case of VR Learning'	③ Checking readiness for class ④ Presenting problems
Visual familiarization	Adapting to vision Checking whether the virtual objects are well seen	Providing virtual objects for testing		

Virtual avatar familiarization (learners, NPC[1]s)	Checking virtual avatars (learners, NPCs) Adapting to manipulation of virtual avatars (learners) Adapting to interaction of virtual avatars (learners, NPCs)	Providing virtual avatars (NPCs) for testing Forming intimacy with virtual avatars (NPCs) through interaction
VR controller familiarization	Checking controller assisted interactions Adapting controller assisted interaction	Providing virtual objects for testing Inducing improvement of VR controller proficiency

Appendix C Final version of proposed VR-based teaching-learning model for distance education, Step 2: Intro (Student Check)

Contents	Description	Methods	Tool /Interaction	Step of conventional model
Checking for Pre-learning and learning goals	Checking the results of pre-learning. Presenting learning goals.	Presenting learning goals through virtual objects related to learning contents. Stimulating interest and motivation of learners.	Provided based on 'Case of VR Learning'	③ Checking readiness for class ④ Presenting problems

Appendix D Final version of proposed VR-based teaching-learning model for distance education, Step 3: Case of VR Learning (Gentrified Active VR Learning)

Contents	Description	Methods	Tool /Interaction	Step of conventional model
Checking the learning contents	Explaining tasks in the virtual story	Motivating learner's interest (e.g., NPC dialogue, narration, task demonstration, etc.)	Input hardware - Keyboard, mouse, joystick - Smartphone - Camera - Eye tracking device - Motion tracking device - HMD[2] (Head Mounted Display) controller Output hardware - HMD - HMD controller - Monitor - Smartphone - Tactile gloves Control input - Button - Touch - Gesture - Sensing data - Controller Watching/Virtual interaction - Timeline annotation (VR memo/sticker/ highlighting) - Recorded motion data (virtual hand/device/ avatar) - Recorded video (virtual object/avatar, 360-degree video) - Sensitive feedback (vibration, pressure, temperature)	④ Presenting problems ⑤ Solving problems ⑥ Applying the results
Providing roles in a virtual story	Guiding the role in virtual story	Improving learner immersion (e.g., NPC dialogue, narration, etc.)		
Virtual machine familiarization	Checking whether the virtual machines are well seen Checking movements of virtual machine according to user's manipulation	Checking the learner's ability to manipulate virtual machines Improving learner's immersion		
Providing practice goals	Providing practice goals in virtual stories	Motivate learning		
Repetition of practice using virtual machine	Performing and repetition of practice using virtual machine. Providing immediate feedback using multiple senses (e.g., vibration or sound)	Improving immersion through feedback. Improving learning effect through repetition.		
Checking the results	Assessing the practice assignment results	Using various assessment factors (e.g., goal score, taken time, posture, etc.)		
Applying the results	Manipulating virtual machine freely using the knowledge acquired in practice	Applying learning knowledge Improving learning effectiveness		

[1] Non-Player Character
[2] Head Mounted Display

Appendix E Final version of proposed VR-based teaching-learning model for distance education, Step 3: Case of VR Learning (Limited Active VR Learning)

Contents	Description	Methods /Strategy	Tool /Interaction	Step of conventional model
Checking the learning contents	Explaining problems in the virtual story	Motivating learner's interest (e.g., NPC dialogue, narration, etc.)	Input hardware - Keyboard, mouse, joystick - HMD controller Output hardware - HMD - Monitor - Smartphone Control input - Button - Controller Watching - Recorded motion data - Recorded video - Recorded 360-degree VR video	④ Presenting problems ⑤ Solving problems ⑥ Applying the results
Providing roles in a virtual story	Guiding the role in virtual story through NPC	Improving learner immersion (e.g., NPC dialogue, narration, etc.)		
Providing assignments in virtual story	Guiding the assignments in virtual story through NPC	Providing step-by-step assignment Improving achievement by providing differential rewards for each step		
Performing the assignment	Performing given assignments through interaction with virtual worlds including virtual objects, NPCs, etc.	Inducing learner-led assignment performance		
Checking the results	Checking result through manipulation or changed virtual object/environment Assigning advanced assignment according to the level of performance results	Providing advanced assignment according to the level of performance results Conducting classes according to the each learner		

Appendix F Final version of proposed VR-based teaching-learning model for distance education, Step 3: Case of VR Learning (Oversized Passive)

Contents	Description	Methods /Strategy	Tool /Interaction	Step of conventional model
Checking the learning contents	Explaining the virtual world to experience	Motivating learner's interest (e.g., NPC dialogue, narration, etc.)	Output hardware - Monitor - Smartphone - HMD Watching - Recorded motion data - Recorded video - Recorded-360 degree VR video	④ Presenting problems ⑤ Solving problems
Watching VR content (video) for learning	Transmitting knowledge through VR content (video)	Providing various viewpoints (e.g., first person, third person) Providing various environment (e.g., real world, virtual world)		

Appendix G Final version of proposed VR-based teaching-learning model for distance education, Step 4: Outro

Contents	Description	Methods /Strategy	Tool /Interaction	Step of conventional model
Assessment	Guidance on how to assess Feedback on assessment results	Instructor's final assessment Conducting quiz, debate, announced or discussion Conducting individual or team assessment	Input hardware - Keyboard, mouse, joystick - Smartphone - Camera - Eye tracking device - Motion tracking device - HMD controller Output hardware - HMD - HMD controller - Monitor - Smartphone - Tactile gloves Control input - Button - Touch - Gesture	⑦ Feedback
Mutual assessment	Providing guidelines for sharing learning processes and outcomes Providing guidelines for sharing feedback	Mutual assessment among learners Mutual feedback on the learning process and out comes		

Organizing key content	Summarizing the key points	Inducing learner self-feedback Inducing learner long-term memory	- Sensing data - Controller Virtual interaction - Timeline annotation (VR memo/sticker/ highlighting) - Recorded motion data (virtual hand/device/ avatar) - Recorded video (virtual object/avatar) - Sensitive feedback (vibration, pressure, temperature)

Appendix H VR IGLOO Model application guide (Checklist), Step 1: VR Preparation

Step	Contents	To-do lists	Methods/Strategy /Tool/Interaction
VR preparation	Design of class content	☐ Learning by controlling virtual device in VR content ☐ Learning by performing step-by-step tasks in VR content ☐ Learning by watching VR content	-
	Learner environment analysis	▪ VR content type ☐ Practice type ☐ Theoretical type ☐ Practice + Theoretical type ▪ Input hardware ☐ Keyboard, mouse ☐ Joystick ☐ Smartphone ☐ Camera ☐ Eye tracking device ☐ Motion tracking device ☐ HMD controller ▪ Output hardware ☐ HMD ☐ HMD controller ☐ PC monitor ☐ Smartphone ☐ Tactile gloves	☐ Distribution of environmental guidelines
	Advance notice of class content	☐ Notice on the contents of the class or the session ☐ Distribution of the learning content material	☐ Class material ☐ Textbook ☐ Video

Appendix I VR IGLOO Model application guide (Checklist), Step 2: Intro

Step		Contents	To-do lists	Methods/Strategy /Tool/Interaction
Intro	Ready VR learning	Checking learner environment	☐ Checking VR environment	☐ Providing question-and-answer window for emergencies ☐ Monitoring to confirm the environment
		Visual familiarization	☐ Checking visibility of the virtual object ☐ Securing learners' time to adapt to vision	☐ Providing virtual objects for testing
		Virtual avatar familiarization (learners, NPCs)	☐ Checking virtual avatars (learners, NPCs) ☐ Securing learners' time to adapt to manipulation of virtual avatars (learners) ☐ Securing learners' time to adapt to the interaction of virtual avatars (learners, NPCs)	☐ Providing test young virtual avatar (NPC)
	Student Check	VR controller familiarization	☐ Checking controller assisted interactions ☐ Securing the learner's time to adapt to the controller interaction	☐ Providing virtual objects for testing ☐ Inducing learners to improve their mastery of controller operation

Appendix J VR IGLOO model application guide (Checklist), Step 3: Case of VR Learning

Step		Contents	To-do lists	Methods/Strategy /Tool/Interaction
Case of VR learning	Common	Checking the learning contents	☐ Providing a story ☐ Explaining the problematic situation	☐ NPC ☐ Narration ☐ Music ☐ Graphics (3D) ☐ Photo (2D) ☐ Videos
		Providing roles in a virtual story	☐ Guiding the role	☐ NPC ☐ Narration ☐ Music ☐ Graphics (3D) ☐ Photo (2D) ☐ Videos
	I. Gentrified active VR learning	Virtual machine familiarization	☐ Checking the operation of the virtual machine ☐ Securing learners' time to adapt to manipulation of virtual machine	☐ Understanding the learner's ability to manipulate virtual machines
		Providing practice goals	☐ Guiding to target score	☐ Motivating Learning
		Repetition of practice using virtual machine	☐ Providing immediate feedback	☐ Enhancing learning effects through repetitive performance
		Checking the results	☐ Assessing the results of a practice assignment	☐ Using various assignment factors ☐ Score ☐ Time ☐ Posture
		Applying the results	☐ Testing learners' ability to apply knowledge	☐ Improving learning effects through application contents
	II. Limited active VR learning	Providing assignments in virtual story	☐ Guiding assignments	☐ Providing step-by-step assignment ☐ Differential reward according to each steps
		Performing the assignment	☐ Doing tasks based on interaction	☐ Inducing learner-led assignment performance
		Checking the results	☐ Checking the results of an action ☐ Assigning advanced tasks based on performance outcomes	☐ Assigning assignments for each learner's level
	III. Oversized passive VR learning	Watching VR content (video) for learning	☐ Transmitting knowledge through VR content (video)	☐ Various viewpoints ☐ First person view ☐ Third person view ☐ Real world ☐ Virtual world ☐ 360-degree video

Appendix K VR IGLOO model application guide (Checklist), Step 4: Outro

Step	Contents	To-do lists	Methods/Strategy /Tool/Interaction
Outro	Assessment	☐ Providing guidelines for sharing learning processes ☐ Providing guidelines for sharing learning outcomes ☐ Providing guidelines for sharing feedback	☐ Instructor's final assessment ☐ Mutual evaluation among learners ☐ Mutual feedback on the learning process ☐ Mutual feedback on learning outcomes
	Mutual assessment	☐ Guidance on how to assess ☐ Feedback on assessment results	☐ Quiz ☐ Announced ☐ Discussion ☐ Debate ☐ Individual assessment ☐ Team assessment
	Organizing key content	☐ Summarizing the key points	☐ Inducing learner self-feedback ☐ Inducing learner long-term memory

Appendix L VR IGLOO model application guide (Checklist): Example of checklist usage

Step		Contents	Checklist Items: To-do lists	Checklist Items: Methods/Strategy /Tool/Interaction
VR preparation		Design of class content	☑ Learning by performing step-by-step tasks in VR content	-
		Learner environment analysis	▪ VR content type ☑ Practice type ▪ Input hardware ☑ Keyboard, mouse ☑ HMD controller ▪ Output hardware ☑ HMD ☑ PC monitor	☑ Distribution of environmental guidelines
		Advance notice of class content	☑ Notice on the contents of the class or the session ☑ Distribution of the learning content material	☑ Class material
Intro	Ready VR learning	Checking learner environment	☑ Checking VR environment	☑ Providing question-and-answer window for emergencies ☑ Monitoring to confirm the environment
		Visual familiarization	☑ Checking visibility of the virtual object ☑ Securing learners' time to adapt to vision	☑ Providing virtual objects for testing
		Virtual avatar familiarization (learners, NPCs)	☑ Checking virtual avatars (learners, NPCs) ☑ Securing learners' time to adapt to manipulation of virtual avatars (learners)	☑ Providing test young virtual avatar (NPC)
		VR controller familiarization	☑ Checking controller assisted interactions ☑ Securing the learner's time to adapt to the controller interaction	☑ Providing virtual objects for testing ☑ Inducing learners to improve their mastery of controller operation
	Student check	Checking for Pre-learning and learning goals	☑ Checking the results of pre-learning ☑ Presenting learning goals	☑ Providing virtual objects related with learning goals
Case of VR learning	Common	Checking the learning contents	☑ Providing a story ☑ Explaining the problematic situation	☑ NPC ☑ Narration
		Providing roles in a virtual story	☑ Guiding the role	☑ NPC ☑ Narration
	II. Limited active VR learning	Providing assignments in virtual story	☑ Guiding assignments	☑ Providing assignments according to each steps ☑ Differential reward according to each steps
		Performing the assignment	☑ Doing tasks based on interaction	☑ Inducing learner-led assignment performance
		Checking the results	☑ Checking the results of an action ☑ Assigning advanced tasks based on performance outcomes	☑ Assigning assignments for each learner's level
Outro		Assessment	☑ Providing guidelines for sharing learning processes ☑ Providing guidelines for sharing learning outcomes ☑ Providing guidelines for sharing feedback	☑ Instructor's final assessment ☑ Mutual evaluation among learners ☑ Mutual feedback on the learning process ☑ Mutual feedback on learning outcomes
		Mutual assessment	☑ Guidance on how to evaluate ☑ Feedback on evaluation results	☑ Quiz ☑ Individual assessment
		Organizing key content	☑ Summarizing the key points	☑ Inducing learner self-feedback ☑ Inducing learner long-term memory

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