

Article

Technology-Enhanced Education through VR-Making and Metaverse-Linking to Foster Teacher Readiness and Sustainable Learning

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Abstract: The main purpose of this paper is to bring pioneering insights into the core line of sustainable education research by investigating the multi-dimensional aspects of teachers' readiness to design technology-enhanced learning environments. In order to achieve this goal, this study documents the experiences of pre-service English teachers in instructional Virtual Reality (herein, VR) content design of K–12 English digital textbooks. Furthermore, it examines how their VR creation can be linked to a metaverse platform for learning adaptivity and sustainable education. The data are collected by pre-/post-surveys as well as reflective papers. The pre-/post-survey responses are analyzed with a *t*-test to determine significance; the reflective paper entries are scrutinized with sentiment analysis and text mining. The study findings suggest that such transformative experiences of VR-Making (herein, VRM) for instructional contents are conducive to capacitate pre-service teachers' technological readiness, 4Cs (Critical Thinking, Creativity, Collaboration, Communication) in digital citizenship, and perceived pedagogical benefits. Based on findings, this study continues to support the need for providing teaching practitioners with hands-on learning-to-teach opportunities with emerging technology as a tool to fulfill sustainable education.

Keywords: sustainable education; emerging technology; teacher readiness; digital textbook; VR; metaverse



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1. Introduction

Technology-enhanced education has played a pivotal role in student learning and development [1]. Following the lead of society, teaching practitioners and policy makers on the ground have constructed the theoretical frameworks and investigated practical strategies on how and why emerging technology should be used more often in learning and teaching. In 2011, South Korea's government launched the 'SMART' classroom project, which is an abbreviation of Self-directed, Motivated, Adaptive, Resource Free, and Technology embedded [2]. It aims to design technology-enhanced learning systems and environments to ensure students' high-quality motivation and active engagement. Among many SMART plans, in an attempt to make course materials and resources relevant in a digital world, the integration of digital textbooks into the K–12 curriculum has become one of the key tasks of the government. After five years of development, application preparation, and preliminary research, some of the existing paper textbooks have been substituted and upgraded to a digital version since 2016. Various digital learning materials including evaluation items and learning management functions have been implemented in K–12 classrooms.

In South Korea, the past 5 years have seen increasingly rapid advances toward digital learning with a textbook. Extensive research shows that the use of a digital textbook has enhanced the quality and efficiency of education, liberating students from individual learning trapped in paper by making classroom instruction and activities more interactive

and adaptive [3,4]. Many teachers have found that a digital textbook is more engaging because it is designed with various multimedia sources such as videos, animations, and audio. Some researchers suggest that it aids students' multimodal learning process and improves their digital literacy skills compared with its counterparts [5–7].

Although there are several advantages of digital textbooks, including interactive features and accessibility on portable devices, several barriers still exist regarding implementation in K–12 education. Multiple studies highlight that inconvenience of using a digital textbook does not outweigh its benefits [8,9]. There are certain technological, infrastructural, and administrative limitations, such as the issue of equal distribution of tablet PCs to every school and the inconsistency of textbook affordability initiatives [10]. In addition, there are some pedagogical concerns and practical issues. For example, one of the most common complaints about the use of a digital textbook on the ground has to do with questionable effectiveness. Despite the availability of a digital alternative, teachers and students still like to use paper because they do not experience significant differences [1,11]. As multimodal learning in a digital textbook is still entrenched in the two-dimensional interaction between a digital content and student learning on the screen, it does not provide a different engagement that students used to have in a paper textbook. Moreover, some teachers have experienced their unclear role and responsibilities in adoption of digital textbooks in classrooms. While there are tremendous efforts to learn about the best strategies and practices for the effect implementation and management of a digital textbook, it is still questionable whether such attempts feed through into the wider public satisfaction in all K–12 settings.

In order to overcome such limitations, since 2018, Augmented Reality (AR hereafter) and Virtual Reality (VR hereafter) contents have been developed and applied in a digital textbook system. A wide range of literature reflects the potentials of integrating VR technology in digital learning because it helps students keep their attention and make learning more fun and exciting [12,13]. However, much uncertainty still lingers over whether the foreseeable future of VR-based education with a digital textbook provides a full immersion and sustainable learning experience for students. At present, little systematic research exists that examines how VR contents in a digital textbook have been used in a K–12 setting in South Korea. As for the scope of application, Social Sciences and Science textbooks only have some VR contents developed and linked to the App called Immersive Contents. This indicates a need to develop VR contents in other subject areas such as English and Mathematics.

All things considered, based on an in-depth analysis of learning contents in middle and high school English digital textbooks, this study showcases what can be converted to VR learning contents. Specifically, pre-service English teachers create VR contents on their own through the use of a 3D creation and coding program, Cospaces Edu. Besides this, for learning adaptivity and sustainability, this research sheds new lights on the role of the metaverse (emerging technology as a fully realized digital world) in the context of transforming one-way interaction between digital content knowledge and student learning to multi-dimensional immersion focused on a social connection and interaction with a teacher and other peers. Through this process, this paper further examines how experiences of VR-Making (VRM hereafter) and metaverse-linking influence technology-enhanced teacher professional development. The research questions that guide this study are as follows:

- (1) What does the process of VRM of English digital textbooks look like?
- (2) How can the product of VRM be integrated into a metaverse platform for learning adaptivity and sustainable education?
- (3) How does VRM affect pre-service English teachers' readiness to use emerging technologies in classrooms?

2. Theoretical Backgrounds

2.1. The Research Trend of VR-Based Education

Virtual reality (VR) is to simulate a realistic experience, or a sense of presence, based on the perceptual senses on which actions are performed. The presence in VR-based interventions is often mediated by inducing the high user immersion of virtual selves and realistic interaction between virtual and real worlds [14]. In the realm of education, a body of practitioners and scholars have experimented how the use of VR technologies can offer a new arena of learning and teaching to cater different pedagogical needs. Along this line, this section delves into examining the comprehensive landscapes of existing literature from 2020 to 2022 to identify the extent to which VR-based instruction can serve as a mechanism to maximize student learning and to develop cognitive and socio-emotional skills. The Web of Science database and VOSviewer mapping software were used to identify the worth of VR in education, and a series of essential keywords were identified from the retrieved bibliometric.

The keywords “virtual reality”, “VR”, and “education” were used to map the research field and to identify prominent thematic areas (see Figure 1). The retrieved word items were manually screened to remove unnecessary terms that seemed irrelevant and to exclude words that appeared less than five times to spatially reveal the structure of the research field. Research from the database, the VOSviewer generated nine clusters with 267 word items and 4469 links, 7539 total link strength. Of the 267 word items, the following words have the high values of the total link strength: “virtual reality” (total link strength 798), “education” (total link strength 596), “performance” (total link strength 526), “students” (total link strength 346), “simulation” (total link strength 332), “augmented reality” (total link strength 294), “system” (total link strength 276), “skills” (total link strength 268), “technology” (total link strength 258), “environments” (total link strength 238), and “experience” (total link strength 227). The network co-occurrence analysis results suggest that the higher links and total link strengths generally correlate with higher occurrences.

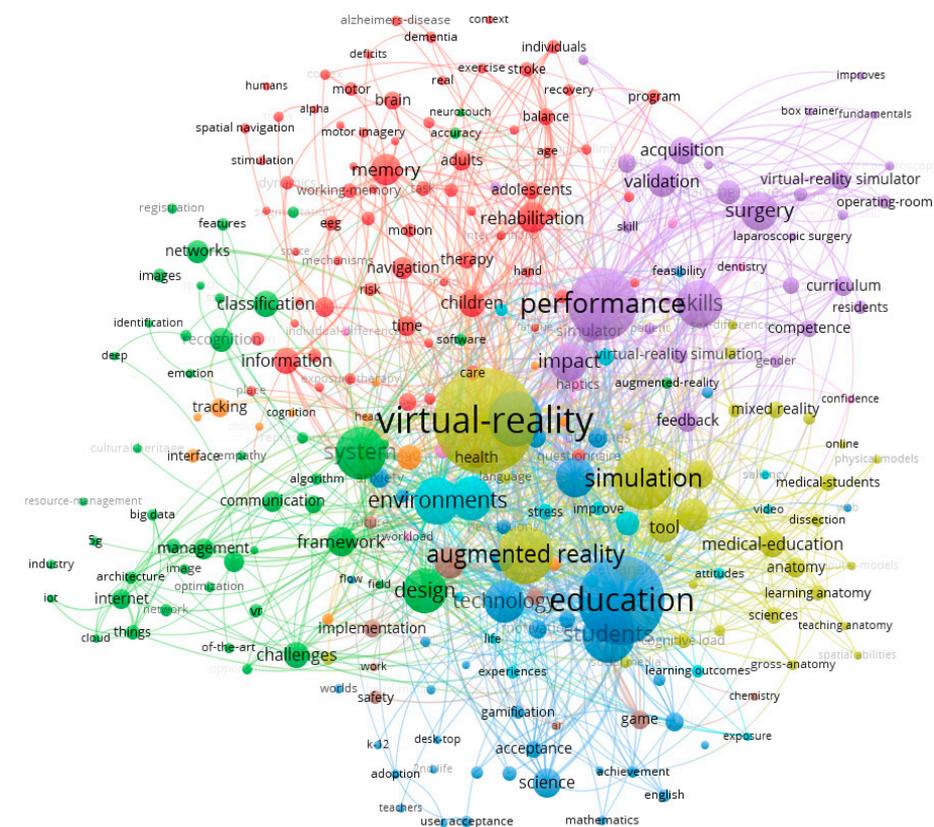


Figure 1. The analysis of VR and education of publications from 2020 to 2022.

Cluster 1 seems relevant to target students of VR-based instructions, and cluster 2 seems associated with technological aspects or embodiment of VR technology. Clusters 3, 5, and 6 are related to educational uses or applications of VR technology in class. Three of clusters, namely, clusters 4, 7, and 9, are more pertained to pedagogical considerations of VR implementation, and cluster 8 is related to main application areas of VR technology (see Figure 2). The prominent keywords derived from the systematic analysis of hitherto publications can be allied with our study variables to achieve sustainable education. For example, the following top keywords, “virtual reality, classroom, environments, experience, education, performance”, and “technology”, served as pillars that intersect in sustainable ways to achieve our research purpose and to yield implications for transformative education.

	Item	Links	Total Link Strength	Occurrences		Item	Links	Total Link Strength	Occurrences	
Cluster 1 (n=70)	Adolescents	39	64	15	Cluster 5 (n=31)	Acquisition	67	131	30	
	Adults	43	67	18		Curriculum	39	63	18	
	Age	22	27	6		Feedback	53	87	22	
	Children	75	130	31		Learning-curve	44	87	25	
	Individuals	25	37	10		Proficiency	34	54	10	
	Older-adults	34	41	11		Retention	21	25	6	
Cluster 2 (n=48)	Variability	20	22	5	Stimulator	52	76	21		
	5G	14	15	6	Skills	102	268	71		
	Artificial Intelligence	20	21	5	Cluster 6 (n=16)	Technical skill	25	36	7	
	Augmented Reality	24	29	8		Attitudes	29	35	8	
	Big Data	22	26	8		Efficacy	37	43	9	
	Cloud	10	16	5		Environments	105	238	71	
	Mobile	33	39	12		Experiences	40	47	9	
	Networks	40	52	24		Exposure	14	19	5	
Software	22	26	8	Improve		31	42	10		
System	125	276	82	Knowledge		55	94	25		
Cluster 3 (n=40)	Achievement	29	40	8	Cluster 7 (n=12)	Behavior	68	94	26	
	Education	162	596	187		Classroom	25	30	7	
	Engagement	41	55	14		Cognition	18	19	5	
	Gamification	36	45	10		Construction	25	32	8	
	Games	60	108	24		Guidance	17	17	5	
	Higher-education	28	35	9		Head	6	6	5	
	Instruction	42	71	17		Interface	17	20	10	
	Intrinsic Motivation	15	17	5		Movement	9	10	5	
	K-12	12	15	5		Tracking	25	35	17	
	Learners	19	22	5		AR	17	21	6	
	Students	120	346	87		Chemistry	8	10	5	
Cluster 4 (n=33)	Teachers	14	15	5	Cluster 8 (n=10)	Future	39	52	11	
	Abilities	27	29	5		Health	51	76	19	
	Augmented reality	120	294	97		Implementation	48	67	16	
	Cognitive load	40	67	12		Safety	21	27	10	
	Gender-differences	30	39	8		Work	13	17	5	
	Mixed Reality	34	48	15		Confidence	16	19	5	
	Physical models	18	26	5		Cluster 9 (n=7)	Haptics	35	48	10
	Simulation	115	332	108			Individual-differences	18	18	6
	Spatial abilities	18	27	5			Learning-environment	20	25	7
visualization	75	147	39	Maintenance	28		44	14		

Figure 2. Co-occurrence word items from 2020–2022 publications on VR research.

2.2. The Cognitive and Socio-Affective Effects of VR-Based Education

VR is said to improve students’ cognitive ability (knowledge retention and academic performance) by merging real worlds with simulated virtual environments. Specifically, several studies have reported that the impact of VR technology in the classroom are found to improve both short- and long-term knowledge retention. In a study conducted

by Pande et al. [15], the test scores of students taught with the VR interventions was increased with an average of 30%, whereas those taught using conventional methods (video) had negligible effects on test performance. The long-term retentions of knowledge gains were also positive (mean score = $81.2 \pm 23.7\%$). They found that virtual learning leads to better knowledge gains and learning outcomes (i.e., in test scores). In addition, Freitas et al. [16] indicated that VR-based immersive technologies can give students possibilities of retaining contents for longer periods of time compared with other methods. Along this line, Rho et al. [17] experimented using VR on manual language learning and found that it can result in increased levels of engagement, confidence, and also memory retention in that VR can be a medium for self-directed acquisition of languages. From these findings, it can be deduced that the use of VR technology can help students with more efficient learning processing and memory retention.

The improved academic performance and achievement are also pointed as a major advantage of using VR in classroom settings. For example, Gloy et al. [18] experimented the extent to which immersion provided by VR technologies can improve learning efficiency in the fields of medical teaching (i.e., anatomy); the study found that VR groups who studied a realistic representation of human anatomy in an immersive anatomy atlas environment performed better overall on anatomical tests than counterpart groups. In this same vein, Ma [19] conducted a comparative experimental study to test the effects of VR technology-based contexts on college students' English learning ability and found a greater academic performance from the experimental students learning in immersive virtual contexts. Along this line, there is another study that reported the positive aspects of VR implementation in teaching complex and daunting subjects with a 37% improvement of the overall test results (astrodynamics) [20].

Not only have some studies pointed out such cognitive benefits of VR, but also other studies have reported the socio-emotional correlates of embedding VR components into instructional contexts. Peixoto et al. [21] noted that immersive VR settings yielded not only learners' positive motivation and learning satisfaction but also high pedagogical benefits for second and foreign language education, compared with other conventional pedagogical practices. In the systematic review of using immersive contents (VR/AR) in language learning, Huang et al. [22] indicated that VR tools can promote language learning as they can offer immersive language learning experience and enhance high levels of motivation and interaction. This reduces the levels of language learning anxiety. The study also reported that the sense and social perception of presence can affect learning satisfaction levels among students. All in all, previous literature supports that VR-based education can be advantageous for students to improve their academic performance, knowledge retention, motivation, and satisfaction by interacting with virtual objects in a 3D environment.

2.3. VR, Metaverse, and Meta-Modality for Pedagogical Purposes and Teacher Readiness

As proven in the previous section, VR-based education can help students with cognitive and socio-emotional benefits. However, in terms of interactivity and presence, it remains important to select a VR program that offers a valuable experience extended through social communication with other people. Except for VR games that can allow synchronous 3D experiences with other users, the majority of educational VR content is meant to deliver semi-immersive experiences to a single user who is connected to his or her physical surroundings.

Although a fully immersive virtual reality may provide a user with more believable experiences with the proper VR glasses, whether it satisfies students who want to experience learning that does occur in the same place or at the same time with other peers, remains unanswered. In other words, students sitting in front of a computer screen or locked in VR headsets with pre-designed digital contents are less likely to experience the psychological sensation of being in a communal space. Moreover, teachers in such environments have no flexibility in terms of learning adaptivity because they cannot change VR environments

or upload relevant learning contents based on students' need and preference. In order to overcome these limitations, the concept of metaverse has gained new attention.

The term "metaverse" is derived from the combination of the words "meta (beyond)" and "universe" referring to a far-reaching future space. It is a virtual enhanced reality in which individuals congregate via avatars for human interaction and cultural exchanges. In a metaverse platform, therefore, students can interact with friends and/or an instructor via avatars to experience learning content, and they can even develop and upload their own work as a 3D object. Likewise, in comparison to earlier virtual asynchronous learning contents, the metaverse incorporates a set of affordances that enable new possibilities of learning enhancement in a virtually enhanced environment [23].

Recently, a number of studies have reported the educational benefits of using a metaverse platform [24,25]. For example, Mystakidis [23] introduced a metaverse course (named Social VR gamification platform in this study) to sustain students' interest and engagement in distance learning of higher education settings. He found that the postgraduate participants reached high levels of engagement in metaverse platforms and the gamified elements seemed to elicit their interest and motivation of learning and autonomy towards academic engagement. He further asserts that although real-time interactions in physical settings have a high pedagogical value that is difficult to replicate in online settings, the metaverse provides a rich alternative, where a tremendous sense of telepresence can be felt by meeting in the same 3D virtual area with other avatars and acknowledging the individuals behind the multi-personas.

Education in a metaverse can facilitate student experiences to ensure multimodal learning opportunities based on a real human interaction. Kress's [26] multimodal learning theory suggests that the more human senses are engaged in learning processes, the better students understand and remember. Supporting multimodality is a crucial part of education in that it helps understand the various ways in which people communicate with each other and express themselves. By combining the various modes such as visual, aural, linguistic, gestural, and spatial, students experience learning in a variety of ways to create a diverse learning style [27]. Recently isolated by the COVID-19 pandemic, some modes of communication in educational contexts are restricted and disruptive, especially in terms of a gestural design (e.g., behavior, bodily physicality, gesture, feeling and affect, kinesics, proxemics, etc.) and a spatial design (geographical meanings, architectonic meanings, etc.).

Indeed, in a distance-learning environment, using digital textbooks (both with and without VR contents) becomes problematic because executing it in a remote place is demanding or even impossible in practice. In this circumstance, transforming learning contents in a digital textbook based on metaversial design may be a feasible alternative. In a metaverse, embodied experiences as avatars have a positive impact on learning based on human gestural behaviors and paralinguistic language use. Furthermore, avatar nuanced interactions can be organized in high-fidelity 3D worlds that are persistent, sophisticated, realistic, or completely synthetic [28]. In terms of multimodality, not only does education in a metaverse evolve other visual, aural, and linguistic modes of communication trapped on a 2D monitor into 3D immersion, but also it increases learning engagement by the gestural mode through avatar movement and enhances learning experiences in 3D spatial design and visualization.

As shown in Figure 3 below, in an English digital textbook, students acquire linguistic information (e.g., This is my mother, This is my teacher, This is my father, etc.) through multimodal learning by clicking on a certain icon on the screen, move on to the next page, and input answers on the crossword puzzle to check their understanding. On the other hand, in a metaverse, students in avatars walk in each to experience learning contents, and by clicking on a 3D object, penguin here, a VR learning content will pop-up that helps students roam around the 3D space to solve a quiz (more details will be presented in the results section.) More importantly, a high level of interaction based on togetherness and presence becomes possible because a teacher is in the same space with students while maintaining a meaningful conversation and interaction.

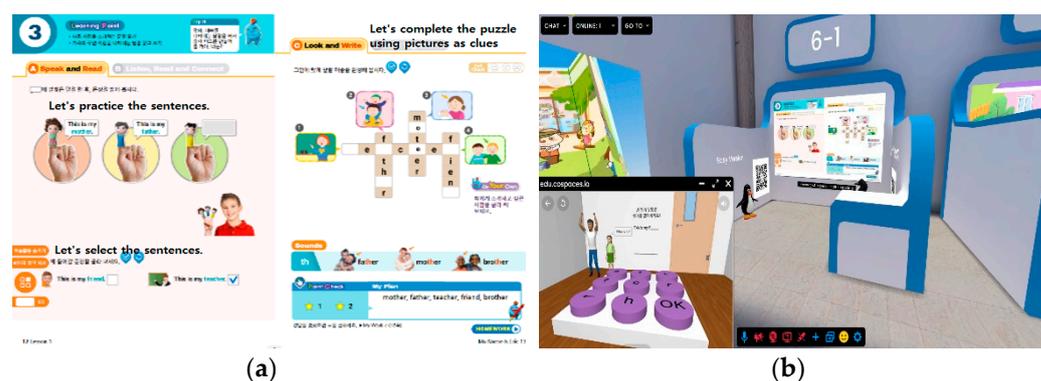


Figure 3. (a) Multimodal learning contents in a digital textbook; (b) Meta-modal learning experience in a metaverse.

All things considered, this study proposes a new term, “Meta-modality”, defined as a set of 3D version communicative modes in teaching and learning practices in a metaverse platform. Supporting meta-modal learning in a metaverse plays a crucial role in implementing VR contents in a digital textbook as it encourages students and teachers to experience multimodal learning contents based on a real human interaction. Cultivating meta-modality application skills is especially vital for teacher practice and preparation in that it has the transformative power of adaptivity and personalization through ubiquitous learning systems. Such technology-enhanced learning can allow teachers to practice sustainability in class by empowering their students to construct knowledge, skills, and values for the long-term consequences. To develop the capabilities of teachers to fully utilize emerging technology affordances, teachers must first be equipped with digital citizenship and 21st century skills, which entails the 4Cs principles: critical thinking, communication, collaboration, and creativity. Therefore, to prepare pre-service teachers to get ready for teaching for transfer and lifelong learning for sustainable education, this study explores the impact of technology enhanced learning-to-teach pedagogy on pre-service teacher readiness and the 4Cs.

3. Methods

3.1. Research Participants and Context

This study was conducted in the Fall semester of the 2021 academic year and included 51 participants from two universities in South Korea (27 students from University A and 24 students from University B). Students in University A are all juniors in the department of English Language and Culture. VR-making and metaverse-linking were implemented in the course Methods and Research on English Textbook, conducted in the Fall 2021 academic year. University B has 24 participants enrolled in a 15-week course, Multimedia-Assisted Language Learning, designed to introduce teacher-trainees to the theories and practice of instructional design for digital technology-embedded English teaching.

Before the semester began, two faculty members from each institution collaborated to create the basic structure of course activities and the research matrix. In both classes, pre-service teachers were asked to conduct a content analysis of English textbooks and explore differences of learning contents between a paper and digital textbook. Furthermore, they were encouraged to discover some limitations of digital textbooks in terms of interactivity and immersion and were asked to create supplementary VR contents, transforming 2D contents in a digital textbook to 3D learning contents.

Before the experiment, students answered the brief survey questions to report their current level of using ICT technology including VR and AR as well as their previous experiences with paper and digital textbooks. The result shows that the mean of 51 students’

ICT knowledge level is 3.46 (out of a 6-point scale). Nineteen students indicated that they like to use digital books, while thirty-eight students preferred using a paper textbook when they are reading and learning. Despite the high preference of paper over digital, more than half of the students answered that a paper book is likely to be substituted to a digital version in the near future (the mean was 3.46 out of 6). For questions asking about previous experiences of digital textbooks and VR-based learning and teaching, no one had used a digital textbook before. Some of the students had experience of VR learning, but nobody had experiences of VR-based teaching or VR contents making. Fifty-one students answered that VR contents would be more effective in English learning and teaching over 2D versions of experience, which indicates that they had some strong motivation to create VR contents. Table 1 summarizes the information of the participants in this study and data collection procedure in the course.

Table 1. Information on participants and research procedure.

	University A	University B
N	27	24
Major	English Language and Culture	English Education
Course	Methods and Research on English Textbook	Multimedia-assisted language learning
Previous Experience of VR-making	None	None
Overall ICT Knowledge	3.41/6	3.50/6
Preference on using digital textbook over paper	3.79/6	4.03/6
Data Collection Procedure	<ol style="list-style-type: none"> 1. Pre-survey on the potential of VR-making and its influence on ICT knowledge and 4C competence 2. Analysis of learning contents in digital textbooks 3. VR making via Cospaces 4. Metaverse linking via Frame VR 5. Post-survey on the experiences of VR-making and its influence on ICT knowledge and 4C competence 6. Self-reflection paper on the overall experiences 	

3.2. VR-Making and Metaverse-Linking Process: VR Maker and Metaverse Platform

To date, most of the previous studies in VR-based education report on the effect of teaching students with pre-designed VR contents. Far too little attention has been paid to teachers' experiences of creating and developing VR contents. Even just a few years ago, the creation and design of VR contents were considered a specialty of the computer science or engineering fields. However, now that API (Application Programming Interface) technology has become widely available to the public, anyone can easily create VR contents without a high level of professional knowledge or coding skills. In this study, English teachers in preparation engaged in the VR-making process by the use of the Cospaces Edu program. Then they connect their VR creation to a metaverse platform, Frame VR, in order to unleash the potential of Meta-modal learning in a 3D space.

3.2.1. Cospaces Edu (VR Maker)

Cospaces Edu is a computer software program that allows students to invent and build their own VR and AR contents that can be interchangeably embedded (see Figure 4). It can also boost software education based on coding programs (Coblox for easy dragging

and dropping colored blocks as well as Script for more advanced coding). Students can experience 3D contents via mobile, tablet PC, desktop, and/or VR glasses. Unlike a metaverse platform, students do not access virtual spaces as avatars but rely on a display, and input devices like keyboards, mice, and controllers. From a user-friendly dashboard with class management tools, Cospaces Edu can simply control and observe student work. It has made a big contribution to creating immersive learning environments all over the world.

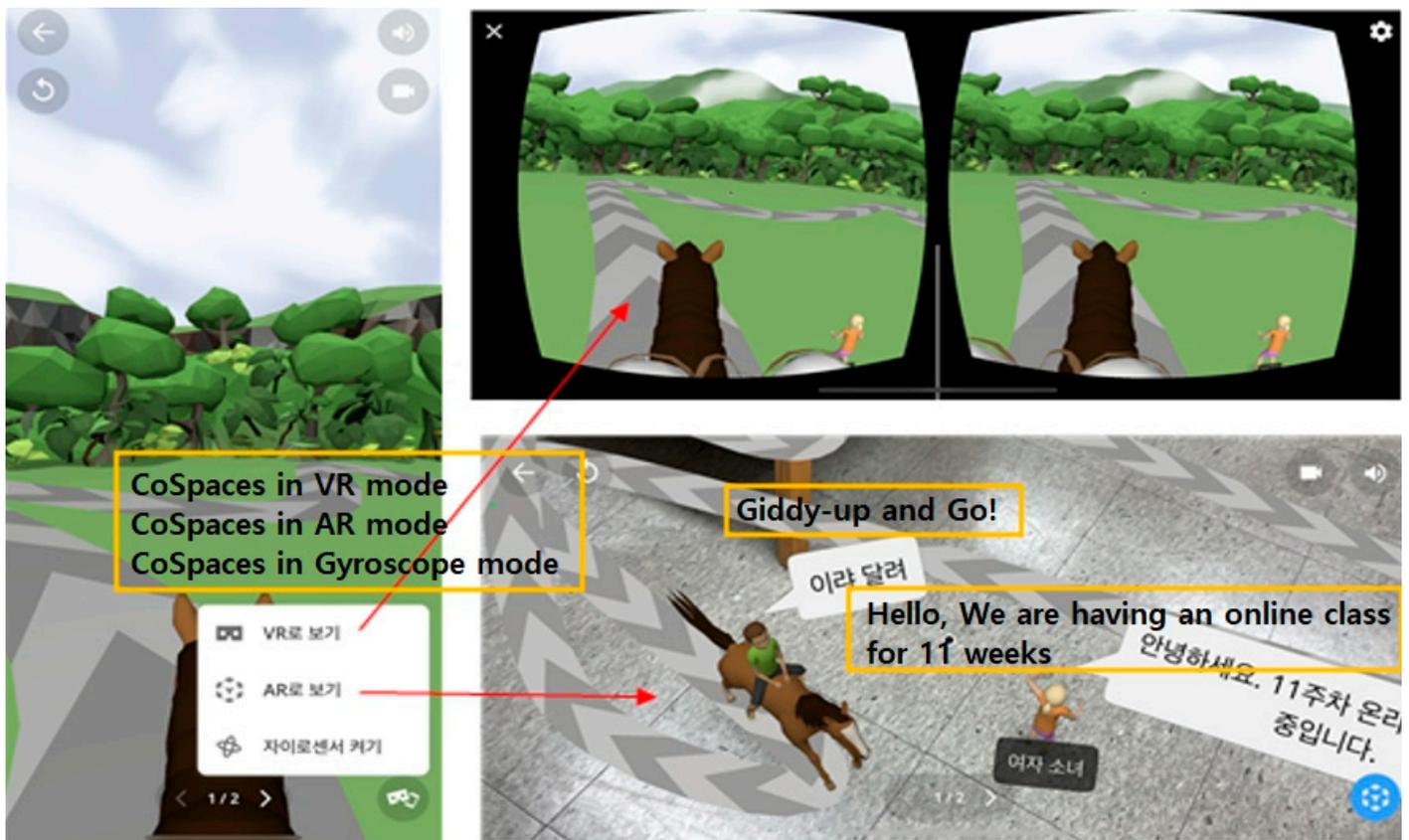


Figure 4. Examples of AR/VR contents by Cospaces Edu.

3.2.2. Frame VR (Metaverse Platform)

Frame VR is a metaverse platform programmed by A-Frame, a 3D production engine. Without downloading or installing a separate program, students can participate in immersive courses and meetings right in their browsers on desktops, mobile devices, and VR headsets (with Oculus Quest 2). As mentioned earlier, with the general VR immersion (i.e., virtual asynchronous learning), students do not always feel social presence with others. In Frame VR, however, students in 3D avatars have a sense of togetherness and presence extended through a social interaction with others (see Figure 5). In addition, Frame VR is widely used as an adaptive learning space suitable for educational purposes as it allows teachers and students in the same place to freely upload a wide range of content to deliver curriculum (photographs, music, PDF, 360 photos and videos, whiteboards, 3D model files, etc.). For sustainable learning experience, Frame VR is an effective platform because it is permanent in nature; students can even meet before and after class to study and connect all in the same place.



Figure 5. Frame VR.

3.3. Data Collection and Analysis

The primary data consisted of a pre/post-survey and reflective papers. First, in order to examine how VRM experience influences pre-service English teachers' readiness to use emerging technologies for both students and their own professional development as a tech-savvy teacher, they were asked to answer a pre- (2nd week) and post-survey (15 week) containing the same questions (see Appendix A for details). The first two questionnaire items asked pre-service teachers to rate (on a scale from 1 to 6) about whether the VRM experience helped their technology competence and ICT application skills development. The next four items asked about pre-service teachers' perceived overall improvements in the 4Cs before and after the invention (i.e., VRM experience). The remaining questionnaire items asked about pre-service teachers' perceived pedagogical benefits and potential values of adoption of VR contents. To test significance of changes and the effectiveness of the VRM intervention, mean responses on a scale of 1–6 were calculated by *t*-test, and the results were tabulated.

Second, students wrote a reflection paper that describes their perceived experiences of VRM processes and product based on the advantages and disadvantages of Cospaces Edu. Furthermore, they wrote about how these experiences influence the (re)construction of their philosophy of what it means to be a tech-savvy teacher and to support technology-embedded education. Then the reflective papers were examined via semantic analysis with Orange 3 and text-mining with a KH coder co-occurrence network diagram. All survey items and reflective paper data were translated into English and the abovementioned procedures formed the interconnected process of data collection and analysis of this study.

4. Results

4.1. The Process and Product of VRM and Metaverse-Linking

This section showcases examples of VRM that pre-service English teachers developed for educational purposes and further describes how VR production can be linked to a metaverse platform.

4.1.1. The Content Analysis for VRM

In order to create instructional VR contents, pre-service teachers conducted the content analysis of 6 English digital textbooks out of 68 digital textbooks being used in middle and high school based on a team consisting of 5–6 students (see Figure 6). As a result, they documented the results of advantages and limitations of learning contents in a digital textbook in terms of multimodal learning, interactivity, and immersion. The rationale for choosing these books as main data is that they are top-selling textbooks in the K–12 setting

of South Korea, and students found them intriguing because of the topic and contents suitable for VR-based learning and teaching.



Figure 6. Textbooks chosen for VR-making.

Based on an in-depth analysis of digital learning contents and after examination of what can be converted to VR contents, pre-service English teachers started to engage in VRM processes by the use of Cospaces Edu in classroom and as an assignment (see Figure 7). Then, with the help of professors, they connected them to a metaverse platform, Frame VR, to facilitate meta-modal learning opportunity and potential in 3D virtual synchronous learning environments.

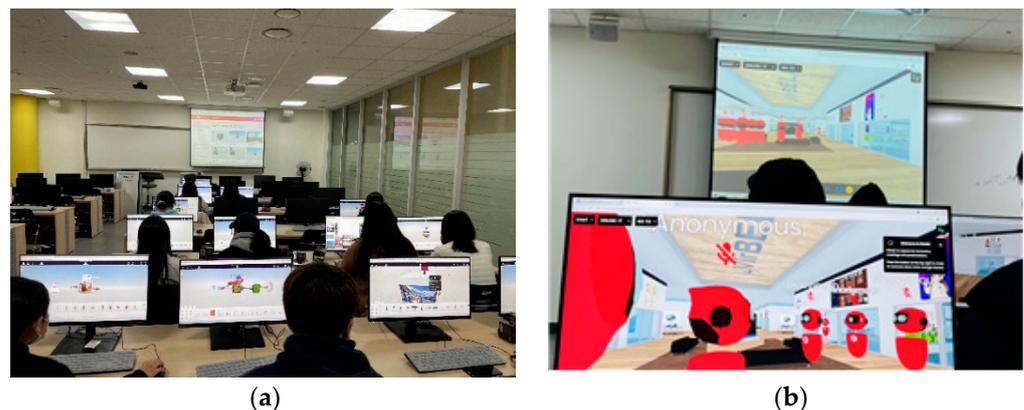


Figure 7. (a) VR-Making process by Cospaces Edu; (b) Metaverse-Linking Process by Frame VR.

4.1.2. The Process of VRM

One of the chapters in a middle school textbook has a reading passage that describes the characteristics of five buildings (Gym, Classroom, Nurse's office, Cafeteria, Library) on a school campus. Inside each building, a teacher, librarian, nurse, and school dietitian greet and explain to students what they do with time information (Figure 8a). Then, on the following page, students check their understanding upon a reading passage, trying to match a main activity in a building with its name (Figure 8b).

By Cospaces Edu, teacher-trainees created five buildings with the same color (Figure 9a) and put 3D human objects in each building speaking the same information provided in a textbook (Figure 9b). Whereas a learner with a digital textbook gains linguistic information on a screen, a learner in this 3D space access the reading information by roaming around the campus, getting into the inside of each building, and clicking on the 3D objects.

In a digital textbook, there is another summative assessment for the reading passage where a student can check the answers by clicking on the blue v-icon in the upper-right hand corner (Figure 10a). However, in a 3D learning space, after a learner visits and looks around each room to gain relevant information, he or she is asked to find another 3D teacher object outside of the buildings in order to submit the quiz (Figure 10b).

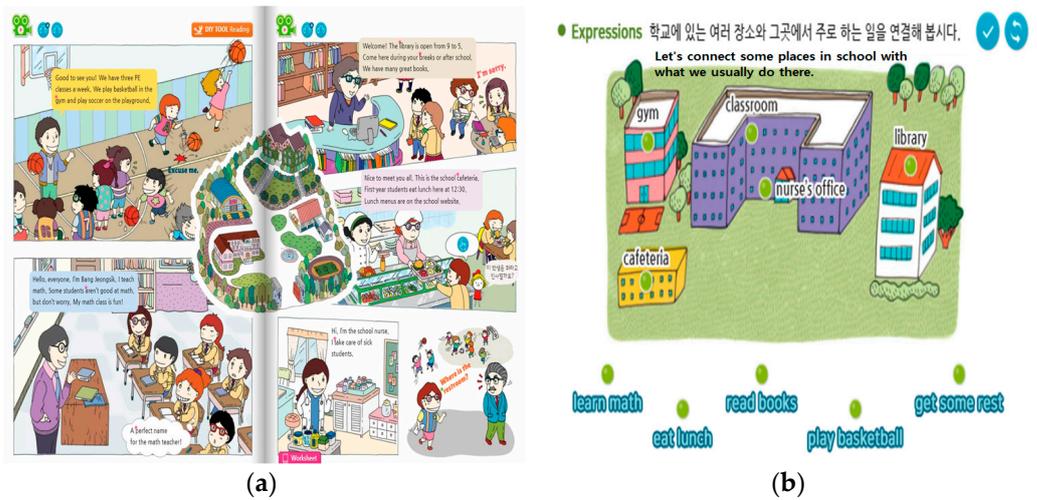


Figure 8. (a) A reading passage that describes the different role of five school buildings; (b) A matching quiz to check students' understanding after reading.

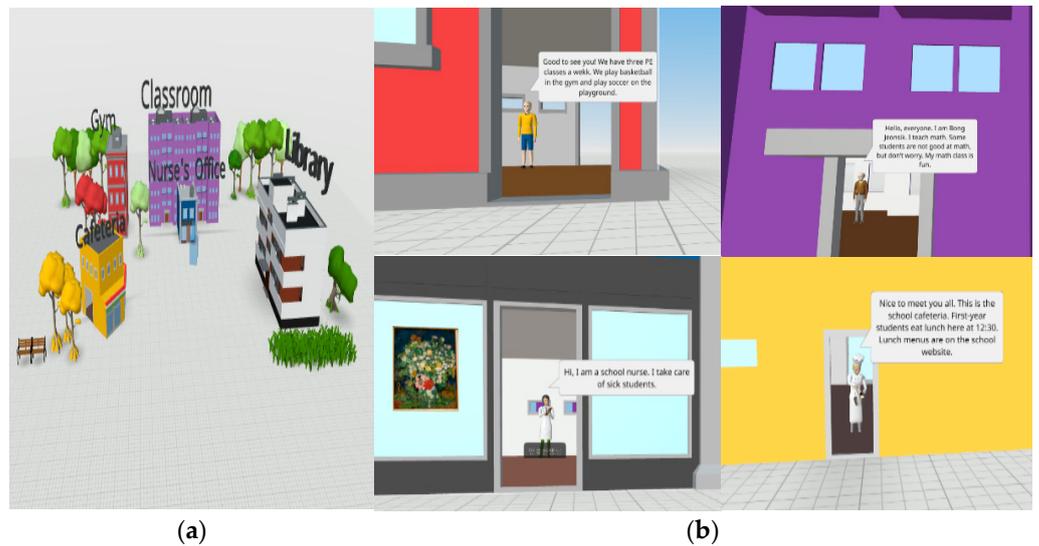


Figure 9. (a) The 3D version of a school campus; (b) The 3D human objects providing the same dialogue inside of each building.

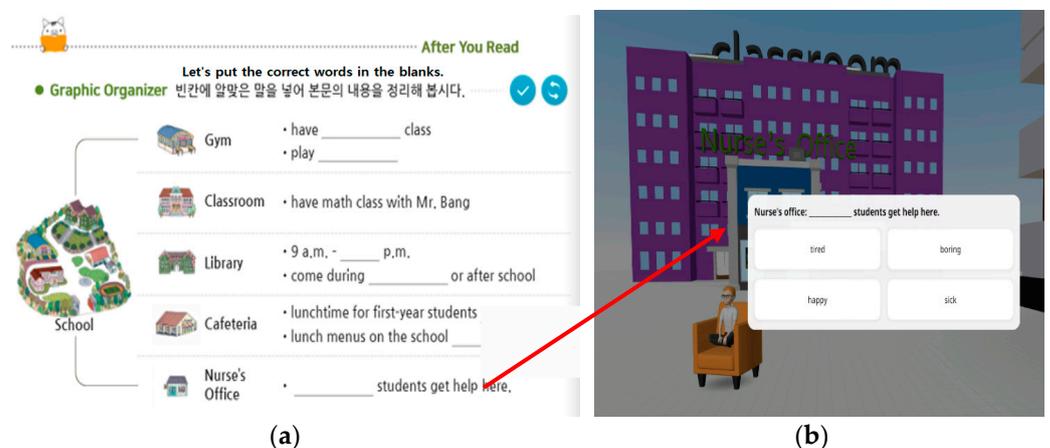


Figure 10. (a) A quiz after reading in a digital textbook; (b) The 3D version of a quiz created and coded by Cospaces Edu.

Another intriguing example in a high school textbook comes from an activity that describes some famous artists. Specifically, on page 135 (see Figure 11a), there is ‘Doing an Information Gap Activity’ that encourages students to do research on six artists’ characteristics and famous works. Then students are asked to make a model dialogue. For an immersive learning content, one of the teacher-trainees created a 3D version of Prado Museum located in Madrid, Spain in which most of Diego Velazquez’s works are displayed. If a learner goes inside the museum, he or she can see Diego’s famous paintings; there is a 3D curator object that induces a click for a quiz.

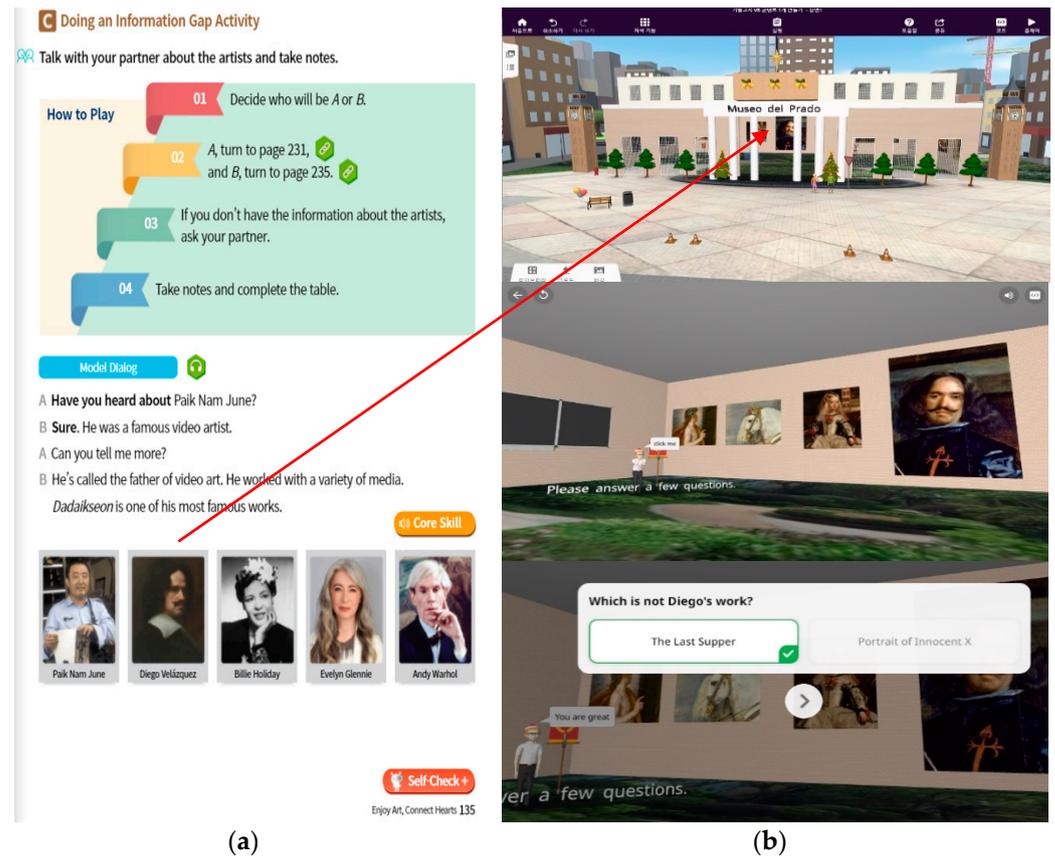


Figure 11. (a) An activity introducing six artists and their masterpieces in a digital textbook; (b) A 3D museum of Diego Velazquez created by Cospaces Edu and a quiz related to Diego’s works coded by Coblox.

4.1.3. The Process of Metaverse-Linking

As seen in the previous subsection, through VR contents created by Cospaces Edu, students will be more likely to experience learning contents with a high level of 3D immersion. However, it is questionable, as the textbook’s prompt requests, whether a student can make a model dialogue and share it with a partner because Cospaces Edu allows a single user to experience 3D contents that does not provide synchronous learning experience based on a sense of togetherness and presence. Therefore, a concept of a metaverse plays a crucial role in creating a learning space where students’ avatars can learn through social communication with other peers and a teacher. For example, in Frame VR below in Figure 12, teacher-trainees put images of a digital textbook and exhibited Diego’s works in a gallery. The learners can get into this space to look around the exhibition, and if they click the plaster figure in the middle of the room (that teacher-trainees uploaded as a 3D object), the link created by Cospaces Edu will pop up so that learners experience the VR contents based on a human interaction.

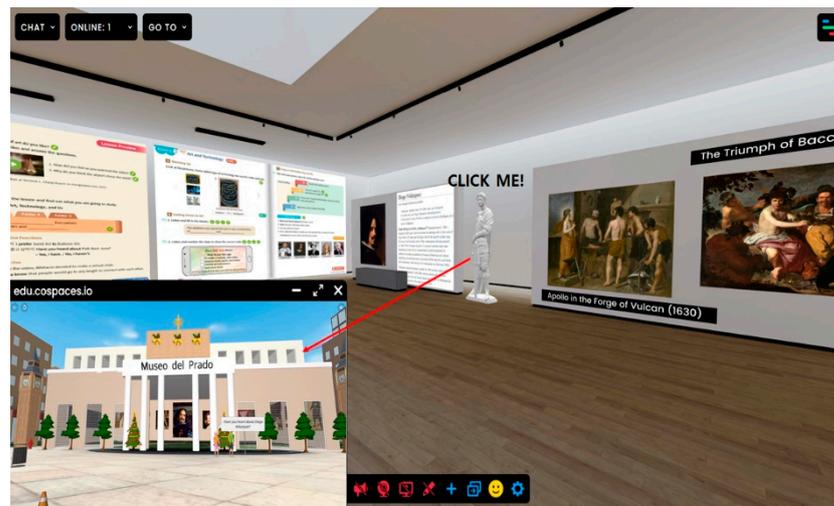


Figure 12. Metaverse linking process.

Beyond connecting a web link to a 3D object, Frame VR allows users to upload a variety of 3D models, 360° pictures, and 360° videos for a higher level of immersion. For example, another participant created a 360° video introduced in a reading passage of the digital textbook (Figure 13a) and put it into Frame VR as a 360° sphere (Figure 13b). The level of immersion in two types is noticeably different. In a digital textbook, if a student clicks the audio icon in the upper-left corner, he or she will only listen to the reading passage. However, in a metaverse, if a student clicks on the 360° sphere, he or she see a VR version of the virtual choir in the reading passage based on a full-immersive experience with the proper VR glasses.

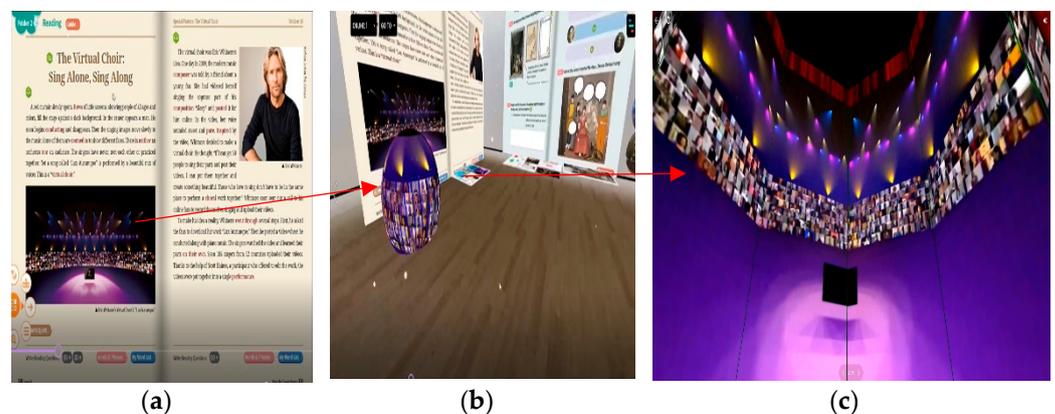


Figure 13. (a) The 2D information in a digital textbook; (b) A sphere object for 3D immersion in the metaverse; (c) VR video that pops up upon clicking on a sphere.

4.2. Changes in Technological Competence, the 4Cs, and Perceived Pedagogical Benefits

This study operationalizes teacher readiness towards technology integration as a multidimensional construct, manifested by existing literature [29–33]. In particular, to gauge the impact of VRM experience on pre-service teachers, this research compared pre/post-survey response results, which is organized into the following four categories: (1) technological readiness, (2) 4Cs, (3) perceived pedagogical benefits, and (4) needs for tailor-made VR instructional contents to cater for specific needs of students.

The overall results indicate that, to some extent, there were improvements in technological competence, 4Cs, and perceived pedagogical benefits of VR before and after the VRM experience, albeit some changes are not statistically significant (Table 2). In terms of technological competence, the pre-service teachers rated above average (3.00) and the

contribution of VRM experience to the technology competence improvement was not statistically significant ($p > 0.05$). This may be attributed to the demographic characteristics of the study participants, who grew up with digital devices on the cusp of the technology explosion. They might be adept at embracing emerging technology.

Table 2. Pre/Post-survey results.

Components	Items	Mean	S.D.	S.E.	M.D	SE.D	<i>t</i>	Sig
Technological Competence	(pre) Technology	3.46	1.056	0.1465	−0.308	0.226	−1.36	0.179
	(post) Technology	3.77	1.215	0.1684				
	(pre) ICT	4.90	0.855	0.1197				
	(post) ICT	5.10	0.781	0.1094				
Digital Citizenship (21st Century Skills) 4Cs	(pre) Creativity	4.55	1.045	0.1464	−0.588	0.164	−3.59	<0.001
	(post) Creativity	5.14	0.749	0.1049				
	(pre) Critical Thinking	4.33	1.108	0.1551				
	(post) Critical Thinking	4.94	1.028	0.1439				
	(pre) Collaboration	4.57	1.005	0.1407				
	(post) Collaboration	5.12	0.840	0.1176				
	(pre) Communication	4.69	0.927	0.1298				
(post) Communication	4.96	0.979	0.1371					
Perceived Pedagogical Benefits (Cognitive)	(pre) Attention	5.08	0.813	0.1127	0.404	0.168	2.41	0.020
	(post) Attention	4.67	1.004	0.1393				
	(pre) Proficiency	4.86	1.020	0.1429				
	(post) Proficiency	4.31	0.927	0.1298				
Perceived Pedagogical Benefits (Socio-affective)	(pre) Engagement	4.71	0.855	0.1198	−0.333	0.183	−1.82	0.074
	(post) Engagement	5.04	0.824	0.1153				
	(pre) Interest	4.96	0.916	0.1282				
	(post) Interest	5.39	0.635	0.0889				
	(pre) Participation	4.65	0.934	0.1308				
	(post) Participation	5.24	0.651	0.0911				
Necessity	(pre) Needs	4.08	1.055	0.1478	−0.725	0.186	−3.90	<0.001
	(post) Needs	4.80	1.020	0.1429				

With regard to the 4Cs, there were slight improvements between pre and post mean scores on all the constructs of the 4Cs; the post-survey identified that the highest mean score was creativity ($M = 5.14$, $SD = 0.75$), whereas the lowest mean score was critical thinking ($M = 4.94$, $SD = 1.03$). The findings suggest that VRM experience gave pre-service teachers more confidence to tap into their creative capacities by extending pedagogical repertoires offered by emerging technologies. On the other hand, the empirical evidence also suggests that VRM experiences did not contribute to much of the development of critical thinking skills. This might be due to the fact that textbooks are often used as objects of authority, which might forbid pre-service teachers to liberate themselves from criticizing the authority.

The participating pre-service teachers also perceived pedagogical benefits that VR instructional contents can provide, such as the ability to get students to participate, be interested in, and engage in their learning processes. Moreover, there was a notable difference in the mean scores of the necessity for the pre ($M = 4.08$, $SD = 1.06$) and the post ($M = 4.80$, $SD = 1.02$) survey results with a statistically significant increase ($t = -3.90$, $p < 0.001$). In other words, the learning-to-teach pedagogy involved in developing VR instructional contents for digital textbooks seemed to raise awareness and needs for tailor-made instructional materials to satiate specific needs of students. These findings suggest that engaging pre-service teachers to participate in creating VR contents can encourage their willingness and readiness.

4.3. Sentiment Analysis of VRM Experience

Aside from pre/post-surveys, the participating pre-service teachers were asked to write two sets (evaluations and reflections) of reflective papers to explicitly draw on their VRM experiences. The emotions conveyed through the texts constituted sentiment

analysis and text mining data (see Table 3). The sentiment analysis was performed with VADER, SentiArt, Liu-Hu, and Multilingual sentiment lexicons. VADER produces emotional polarity with four sentiment metrics: positive, neutral, negative, and compound scores. SentiArt, based on the vector space models, allows to represent prototypes of emotional valence. Liu-Hu computes a single standardized score of sentiment from a lexicon-based technique [34].

Table 3. The sentiment analysis results with VADER, SentiArt, and Liu Hu.

Classifier/Method		Evaluations (Pros and Cons)			Reflections		
		Mean \pm SD	Min	Max	Mean \pm SD	Min	Max
VADER (Polarity)	Positive	0.16 \pm 0.08	0.00	0.40	0.19 \pm 0.04	0.12	0.28
	Negative	0.09 \pm 0.07	0.00	0.23	0.02 \pm 0.02	0.00	0.07
	Neutral	0.75 \pm 0.10	0.50	0.89	0.79 \pm 0.05	0.71	0.87
	Compound	0.44 \pm 0.54	−0.62	1.00	0.97 \pm 0.02	0.92	0.99
SentiArt (Emotion)	Sentiment	0.05 \pm 0.22	−0.36	0.68	0.09 \pm 0.09	−0.10	0.27
	Anger	0.37 \pm 0.16	−0.10	0.65	0.35 \pm 0.11	0.15	0.54
	Fear	0.68 \pm 0.14	0.38	0.94	0.69 \pm 0.09	0.52	0.87
	Disgust	0.31 \pm 0.12	0.00	0.55	0.32 \pm 0.10	0.12	0.49
	Happiness	1.10 \pm 0.21	0.75	1.70	1.00 \pm 0.09	0.86	1.17
	Sadness	0.81 \pm 0.13	0.59	1.14	0.72 \pm 0.11	0.52	0.90
	Surprise	0.23 \pm 0.16	−0.21	0.59	0.24 \pm 0.13	−0.08	0.53
Liu-Hu	Single	1.38 \pm 3.24	−8.00	11.76	1.90 \pm 1.64	0.00	6.29
Multiling	Single	1.52 \pm 3.50	−6.67	10.81	2.39 \pm 1.86	0.00	6.60

First, VADER computes a continuous univariate sentiment score, ranging from positive to negative values from a word-list- and rule-based procedure and appends a total sentiment score or compound. For reflection entries, the sentiment analysis of VADER displays that the neutral sentiment ($M = 0.79$, $SD = 0.05$) was higher than the positive sentiment score ($M = 0.19$, $SD = 0.004$), which was higher than that of the negative sentiment ($M = 0.02$, $SD = 0.02$). The compound score ($M = 0.97$, $SD = 0.02$), a metric of the total sum of the lexicon ratings that were normalized between -1 and 1 , was close to 0.97 , indicating the positivity of the experience. Gauging from the VADER sentiment scores, VRM experience seems to be quite positive for pre-service teachers.

Second, the analysis of SentiArt, which is based on vector space models to compute a multivariate value for each word, shows marked emotions. In particular, the emotional potentials conveyed from the two sets of the reflective journals suggested that happiness was the highest in both evaluations ($M = 1.10$, $SD = 0.21$) and reflections ($M = 1.00$, $SD = 0.09$). The analysis of SentiArt highlighted the fact that hands-on VRM experience can provide intrinsic motivation for pre-service teachers, which can have a longer-lasting effect. Such experiences can act as an impetus for sustainable change and contribute to the development of pedagogical competence, which can bridge the perennial nexus of learning-to-teach practices and actual classroom implementations.

Third, the Liu-Hu scores, computing from a lexicon-based sentiment analysis, indicate quite positive univariate sentiment features (lexical valences) with logistic regression. The single normalized sentiment scores in the two sets of reflective papers—evaluations ($M = 1.38$, $SD = 3.24$) and reflections ($M = 1.90$, $SD = 1.64$)—indicate that the pre-service teachers perceived VRM experience as positive.

Lastly, the original non-translated reflective papers were also examined via multilingual sentiment analysis. The result shows that the mean scores of the participants' affective attitude were 2.39 ($SD = 1.86$, $Min = 0.00$, $Max = 6.60$) for reflections and 1.52 ($SD = 3.50$, $Min = -6.67$, $Max = 10.81$) for evaluations, which indicate that the majority were quite positive about the VRM experiences.

As sentiment analysis with VADER is sensitive to not only polarity (positive/negative) but also intensity (strength) of emotions, a scatter plot of sentiments was used to statistically display the univariate sentiment values (Figure 14). The x -axis denotes positive scores whereas the y -axis denotes negative scores of the reflective papers on evaluations. The findings show the left side of the density plot deviating from the line. This can computationally suggest that VRM experience seems to yield quite positive responses.

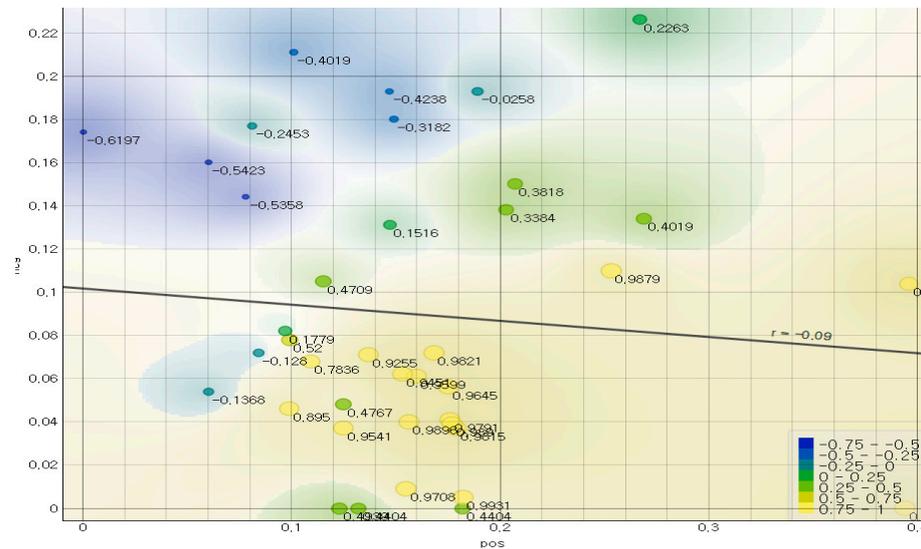


Figure 14. The VADER analysis results in a scatter plot.

4.4. Text Mining of VRM Experiences

The participants' reflective papers were also analyzed via text-mining software KH-Coder for co-occurrence network, which enables drawing a network diagram with high degrees of co-occurrence through connected lines or edges. In a co-occurrence network, a larger circle represents a higher frequency while a thicker or bolder line between words indicates a stronger co-occurrence.

The co-occurrence network in Figure 15 displays the associated relationships between words and variables. The most noted and frequently addressed words in reflective papers were "student", "teacher", and "textbook". Several characteristic words such as "fun", "interest", "learning", "class", "culture", and "participation" appear in the co-occurrence network and such positive words might exude pre-service teachers' beliefs that VR instructional contents can motivate students to learn through participation and sustain interest in their own learning. In addition, some tangible words such as "culture", "museum", and "art", directly reflect the participants' actual tasks of their experiential VRM learning. This indicates that such concrete learning-to-teach practices can stimulate pre-service teachers to reflect upon the experience, which can become a catalyst to fine-tune their pedagogical repertoires and professional competence for sustainable education.

Moreover, the co-occurrence structures also suggest that "book" co-occurred with "future", "skill", "situation", and "thought". This implies that pre-service teachers seem to be conscious that textbooks should seek future skills and sustainability to secure learners' interest. In this study, the researchers designed the reflection paper tasks in a way for pre-service teachers to record their understanding and express their appreciation of the VRM experience analytically; these insights gathered from the text mining results do have the potential to shed light on the nuanced psychological and developmental aspects underlying technology-enhanced learning-to-teach pedagogy.

service teachers' professional development so that the implications can have a much wider audience and message of going beyond the initial research assumptions.

Teachers are key agents and also gatekeepers to determine what enters and gets into the classroom. Therefore, teacher readiness is the first and foremost requirement to maintain sustainable education to provide equal opportunities for learners to obtain continuous learning amidst the ongoing influx of technology shifts. Along this line, this study examined pre-service teachers' VR-making and metaverse-linking experiences as a lens to explore the complexities of teacher readiness. Notwithstanding some limitation such as a small number of participants and technical restraints of the VR maker and metaverse platform, the results are encouraging in that this study presented the impact of the technology-enhanced learning-to-teach pedagogy on teacher readiness to light from not only cognitive, but also affective perspectives. Such approach may provide teacher-educators and policy-makers with necessary empirical evidence to design technology-enhanced learning systems and environments.

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Appendix A

Table A1. Pre-/Post-Survey on Technology-enhanced Learning-to-teach Pedagogy.

Factor	Questions
Technological Competence	Please rate your technology-enhanced competence.
	I think that VRM (VR-Making) experience will help my Information Literacy and ICT Skills.
4Cs	I think VRM experience will help develop my creativity.
	I think VRM content creation experience will help develop my critical thinking skills.
	I think VRM content creation experience will help develop my communication skills.
Pedagogical Benefits (Cognitive)	I think if learning content is implemented using VR technology in English digital textbooks, students' concentration in class will increase.
	I think if learning content is implemented using VR technology in English digital textbooks, students will improve their English skills.
Pedagogical Benefits (Socio-affective)	I think if learning content is implemented using VR technology in English digital textbooks, students will become more actively engaged in their learning.
	I think if learning content is implemented using VR technology in English digital textbooks, students' interest in learning will increase.
	I think if learning content is implemented using VR technology in English digital textbooks, students' participation in learning will increase.
Needs	I believe it is absolutely necessary for English teachers to develop VR contents for more effective learning adaptivity and sustainable education.

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