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Digital Experiential Learning for Sustainable Horticulture and Landscape Management Education

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Abstract: During the COVID-19 pandemic, horticulture and landscape management programmes in higher education experienced a huge drawback because of the impossibility of organising field studies and conducting site research. To pursue a more sustainable method of teaching, immersive technology such as augmented reality (AR) and virtual reality (VR) has been increasingly adopted as an effective approach for multimodal experiential learning. This study examines student perceptions on the use of digital technology in team-based hybrid learning to achieve sustainability in tree management using data collected from students of horticulture and landscape management in a higher education institute in Hong Kong. Key theoretical principles on Kolb's experiential learning cycle as an interactive process are discussed, followed by an empirical analysis of student survey results. This research deepens the understanding of how immersive technology enhances both environmental sustainability and learning innovation. The results demonstrate that innovative ideas in instructional methods such as ARVR simulation can enhance the environmental sustainability of how tree management can be conducted, promoting a more environmentally conscious, experiential, collaborative and digital learning experience in higher education.



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Keywords: environmentally sustainable learning; virtual experiential learning; immersive technology in teaching; virtual reality in tree management; horticulture landscape management education

1. Introduction

The COVID-19 pandemic has challenged the traditional concepts of learning environments and pedagogical approaches in an unprecedented manner, especially in courses that have been relying heavily on field trips, such as horticulture and landscape management. Course offerings have been shifted abruptly from face-to-face classroom teaching to multimodal formats across the spectrum on digital platforms and this trend is expected to continue in the post-pandemic new normal [1,2]. To continue quality education with practical field work in a sustainable manner while students are in social isolation, educators have quickly explored new pedagogies, technologies and tools to sustain the practical elements of the curricular content [3–5]. Among the popular digital interventions in recent e-learning platforms [6], higher education has increased the adoption of immersive technology as the new paradigm in virtual experiential learning [7]. Although there has been extensive work studying the best practices and the impact of online learning on students' motivation and learning outcomes [8–10], the design and delivery of experiential learning opportunities afforded by immersive technology in higher education remain a unique challenge for practitioners. This study examines the student perceptions of immersive educational technology used in a horticulture and landscape management higher education programme during the COVID pandemic. Based on the analytical framework of Kolb's experiential learning theory (ELT) [11], this research aims to explore the connection between the use of immersive technology and the theoretical underpinnings of sustainable

teaching and learning. By examining 128 survey questionnaire results from students on the educational benefits of a pilot immersive experiential learning programme in a self-funded higher education institution in Hong Kong, this paper adds academic knowledge to the technological affordances of immersive technology for holistic experiential learning and enlightens the potential of this sustainable practice for future synchronous team-based hybrid learning in horticulture and landscape management education.

Under the rapid urban development in Hong Kong in recent decades, horticultural land has become increasingly scarce in the city landscape. The industry of horticulture management has been witnessing a profound demand for more sustainable practices for landscaping and plantation management education. Nowadays, professionals in the industry are expected to possess a strategic mindset on how to carry out horticultural practices to meet the triple bottom line of environmental, social and economic sustainability [12]. The high awareness among the public of the importance of management of trees and plantations and their impact on the overall sustainability of urban development have prompted horticultural education to put more recognition on its curriculum and teaching practices to meet the evolving demands of new knowledge and skills inventory.

Higher education in horticulture is striving to nurture a new generation of horticultural specialists and arborists with holistic mindsets of plantation management and an organic understanding of the species-diverse and uneven-aged plant systems. The curriculum of horticulture and landscape management in Hong Kong has been expanding and undergoing a series of vigorous reorganisations to embrace a more practical approach to vocational and professional education. As an applied subject with great reliance on hands-on practice through field trips and laboratory training, horticulture educators have been actively exploring the unique potential of immersive technology to provide experiential learning opportunities to support the curriculum enrichment sustainably and transform the learning experience.

As virtual plant modelling has reached its mature development [13] and students are now granted easier access to immersive systems and devices [14], virtual experiential learning of plantation management is now widely used to supplement traditional teaching in horticultural education [15–18]. As a signature pedagogy of horticultural education, team-based learning has already been widely adopted where students complete pre-work and attempt in-class activities individually and then work together in teams to solve applicational case studies [19]. Team cohesion is crucial to the process, as it was shown to be a significant predictor of team academic performance [20,21]. Therefore, the enablement of cross platforms communications and collaborations is important in the digitalization and virtualisation of horticultural education, by which learners can develop soft skills through organic interpersonal interactions and team-building events in the VR environments.

The new technologies and advanced virtual plant modelling have fundamentally revamped the teaching and learning approaches of horticulture. Their applications in education enable students to conduct practical training in the virtual world without geographical and weather constraints. More importantly, the interventions shorten the overall learning period as they allow students to have instant feedback by observing the progressive changes of their simulated cultivars condensed in minutes right after their experimental practices. Therefore, digital experiential learning offers sustainable practices by mitigating environmental damages to sensitive landscapes, reducing carbon emissions of remote field trips, and enriching the feedback assessments.

2. Literature Review

2.1. *Affordances of Immersive Technology in Higher Education*

Immersive technology, which comprises virtual reality (VR) and augmented reality (AR), is an umbrella term used interchangeably with extended reality. Its applications in education integrate the learning environments and human interactions through computer technology and peripheral perceptual devices. Dichotomously, VR immerses users in completely virtual environments constructed with fidelity graphics and interactive content,

whereas AR overlays virtual content onto people's perceptions of the real world. However, their uses in education are found increasingly blended to provide more comprehensive educational content and support curriculums under different learning scenarios [2,22–25].

Immersive technology can be a powerful and sustainable pedagogical tool that allows students to experience situations and environments directly, which cannot be granted in a traditional classroom setting. The early attraction of immersive technology in education came from its capacity to elude dangers and ethical concerns in professional training when learning by doing in real scenarios poses significant risks or moral questions [26,27]. Immersive technology by simulations provides a safe place to learn as it affords learners to practice and repeat complex and risky tasks that are intolerant to errors and accidents in real life. Moreover, VR technologies have untied the hands of education practitioners to provide experiential learning opportunities anywhere and anytime that are no longer bounded by geographical or physical possibilities [28,29]. In a few clicks of digital devices and the aid of peripheral hardware, e.g., VR headset, VR controller, VR haptic gloves, wireless trackers and adaptors, students can now explore and experience different learning scenarios with experiential curricular content in any single location conveniently.

Dalgarno and Lee [30] have attempted the construction of a model of learning in virtual learning environments (VLE) as the conceptual framework to support the further exploration of its underlying pedagogy and design principles. Although their model was established upon the aggregate knowledge of earlier-dated 3D desktop VLEs, it is applicable and readily extended to cover the latest developments in immersive VLEs. Their work started by identifying the defining characteristics of VLEs and outlined the subjective learner experience in this virtual digital space. The first unique characteristic, representational fidelity, concerns how the virtual world replicates the real world in the visual, spatial, audio and kinaesthetic aspects. The second characteristic, learner interaction, denotes whether users could seamlessly engage with the virtual space, including aspects such as navigation in VR, communication and manipulation of virtual objects. The sensory simulations and embodiment of actions lead learners to construct their avatars in the virtual world and create their senses of presence and hereby affords the learning tasks to take place. Studies suggested that the applications of extended reality in education can help enhance learners' motivation and engagement [31,32]. Moreover, these improvements could be further boosted by the gamification of virtual learning modules [33,34] or with enhanced social interaction features in digital learning platforms [35]. Therefore, immersive technology could enrich the behavioural, cognitive, and affective dimensions of learning by creating vivid first-person presence and mediating interactions with computer-generated objects and structures in VLEs.

Given the fast advancements of immersive technology in education, up-to-date systematic reviews that examine its characteristics and utilisation are essential to affirm its influences on learning outcomes and student attainments. A recent review of immersive educational technology in remote learning of higher education encapsulates that the use of AR and VR in distant learning can bring a significant enhancement in practical, spatial or kinaesthetic skills acquisition and student engagement [36]. However, there are two prerequisite conditions to meet for unleashing the full potential of immersive technology in sustainable horticulture education. First, both teachers and students need to be well supported with training resources and allowed sufficient time to get familiar with the new technology during the transition. Second, rather than a direct migration of curricular content of the traditional didactic course into virtual space, the overall curriculum must be flexibly redesigned and reorganised subject to the unique characteristics of VLEs. Another review, which focuses on comparing the learning outcomes under head-mounted device based immersive VR with other less immersive pedagogical methods, reaches a similar conclusion [37]. Based on reviewing 29 selected experimental studies of head-mounted immersive educational technology published from 2013 to early 2019, the study affirms that immersive VR is most effective in facilitating cognitive learning activities where procedural skills, high visualisation, experiential understanding and spatial competency are required.

In general, most of these experimental studies recommended an extended exposure, rather than a one-off intervention, that would help learners to overcome the learning obstacles resulting from the novelty of immersive technology. Although students today are more technology-savvy than the previous generations, some complaints of cybersickness and physical discomfort from wearing a head-mounted device were occasionally reported. Studies also indicated that the lack of well-developed content, limited university resources and improvised designed software and hardware were major issues that negatively affected the learning experiences and outcomes [38–40].

2.2. Kolb's Experiential Learning Theory

One of the signature pedagogies in horticulture and landscape management is experiential learning. While Kolb's ELT is one of the most widely mentioned learning theories for virtual learning [41], there is ample empirical evidence signifying that immersive VR is effective in accomplishing the learning outcomes as depicted in the theory [42]. ELT articulates the creation of knowledge as a process of grasping and transforming experience in realistic situations [11]. By integrating ideas from empiricism, constructivism and behavioural science, the theory is grounded on six suppositions [43]. First, learning is best apprehended as a process, but not conceived as an outcome. Second, all learning is relearning, which is founded on previous knowledge and ideas. Third, learning is an adaptation process where learners resolve conflicts and disagreements when their pre-existing beliefs are challenged by the new experience. Fourth, learning is a holistic process that involves thinking, feeling, perceiving and behaving. Fifth, learning occurs as 'synergetic transactions' between learners and environments. Learners assimilate new experiences and reshape their existing concepts. Sixth, knowledge is not transmissible as static concepts and ideas, whereas learners must create their own knowledge. Based on these propositions, ELT details a learning cycle where students go through four different learning modes that are mutually supportive. It is an iterative and interactive process with neither a definite beginning stage nor an end stage (Figure 1):

1. *Concrete Experience (CE)*: Students participate in tasks where they get hands-on experiences from problem-solving without prejudices or bias.
2. *Reflective Observation (RO)*: Direct experiences gained by doing in the CE stage do not automatically become new knowledge. Students must observe and review their experiences introspectively. Through conscious reflections, they make meanings from the experiences.
3. *Abstract Conceptualisation (AC)*: Students resolve conflicts and tensions by integrating their observations and reflections on the new experience with their pre-existing beliefs and knowledge. They generalise knowledge from previous experiences and develop new concepts and theories in this stage.
4. *Active Experimentation (AE)*: Students plan and carry out experimental activities to test and validate the newly formed concepts and theories. The experimentation feedbacks new experiences and thus starts another experiential learning cycle.

Kolb's ELT provides valuable inspiration and guidance for educational VR design and development. However, there are also critiques on the lack of pedagogical underpinnings of virtual experiential learning [44–47]. One major dispute over the use of immersive technology in education is the validity and reliability of knowledge conversion from a virtual experience to real-life applications [48]. Scholars doubt that there was little solid theoretical explanation that could adequately connect learning in an immersive digital space with an experiential learning process, as the epistemic relationship regarding the transformation of virtual experience into real-world knowledge was unresolved [41]. From the student perspective, it is reported that although they welcomed the use of immersive technology in their learning, they did not believe that it can substitute for real-life training and suggested it should be applied as a supplementary component to support the curriculum implementation [49–51]. Besides, the current application of immersive VR in education focuses mainly on affording the learning modes of concrete experience

and active experimentation without sufficiently addressing the internal stages of reflective observation and abstract conceptualisation. Findings from the design thinking workshops on codesigning VR learning applications discovered that participants had encountered great difficulties when they tried to incorporate reflection and abstract elements into the design [52]. Their finding has important implications as it revealed that immersive VR remained controversial as an appropriate venue for the higher-order cognitive learning process to take place.

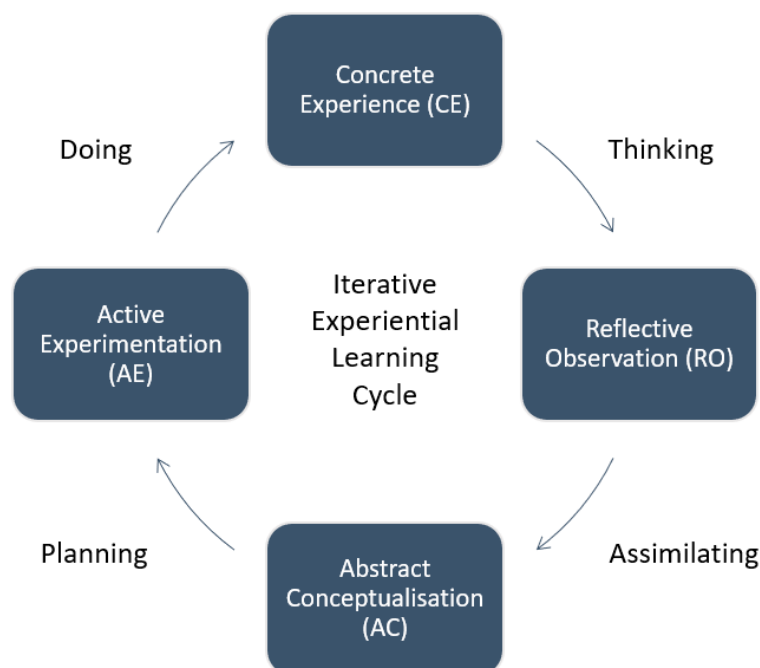


Figure 1. Kolb's Experiential Learning Cycle.

3. Materials and Methods

3.1. Sustainable Experiential Learning in Horticulture Landscape Management

This paper investigates the effectiveness of immersive technology for sustainable experiential learning by comparing student feedback on a tree management course via a traditional learning format versus hybrid learning with the extensive use of ARVR technology during the COVID transition. The original course was organised with a comprehensive focus on lectures, tutorials and physical field trips before the COVID pandemic. The basic idea of the course structure was to first prepare students with theoretical background knowledge of tree impact, tree protection and tree management and supplemented with tutorials to facilitate their understanding of these abstract concepts through interactive discussions with peers and formative feedback from teachers. The new course retains mostly the organisation and structure of the original curriculum but adopts a mixture of virtual field trips, mock laboratory experiments and virtual immersive training to support experiential learning during the pandemic (Table 1). The ARVR application focuses on enhancing students' abilities to adopt a contextual approach in tree selection, planting, training, fertilisation, pest and pathogen control, pruning and risk assessment and management in addressing diverse urban challenges and critical components of urban sustainability and resilience. Under the new course, students analyse real case scenarios in virtual tours and keep abreast of the current technology, latest industry practices in tree management and smart urban forest management.

Table 1. The new tree management course designed with Kolb’s experiential learning theory as the pedagogical foundation.

Course Components	Learning Tasks and Activities	Approach
Theoretical foundations	<ul style="list-style-type: none"> • Introduction to arboriculture and tree management • Tree maintenance and risk assessment • Tree planting and management of nursery in an urban context • Water management • Soil management 	Individual-based online lectures and in-class exercises
Experiential activities	<ul style="list-style-type: none"> • Virtual field trips to analyse real case scenarios • Immersive VR training e.g., tree pruning and transplanting sessions for practising skills and rectifying proposed tree management solutions • Mock laboratory experiments, e.g., soil analysis, mycology testing, etc. 	Hybrid team-based inquiry learning
Critical reflections	<ul style="list-style-type: none"> • Approaches to tree management and risk assessments • Interactive discussions on case studies • Summative reflective sessions after virtual field trips, laboratory experiments and training 	

The design of the pilot virtual course adheres to Dalgarno and Lee’s design principles, focusing particularly on the enhancement of first-person presence and interaction in the virtual world. To virtualise the natural scene of field trips, the design duplicated landscapes of local sites with the inclusion of commonly found forestry trees, plants, fungus and artificial objects such as signages, recreational fixtures and other infrastructure features. During the virtual tour, students can navigate and move freely around the scene, and change their gaze with the head-mounted device (Figure 2). On the kinaesthetic aspect, learners can embody their actions via hand peripheral devices to practice tree management techniques such as tree pruning and tree felling. The fidelity of the virtual environments and interactivity with digital objects are both improved and thus lead learners to better construct their avatars in the virtual space and create their senses of presence (Figure 3).

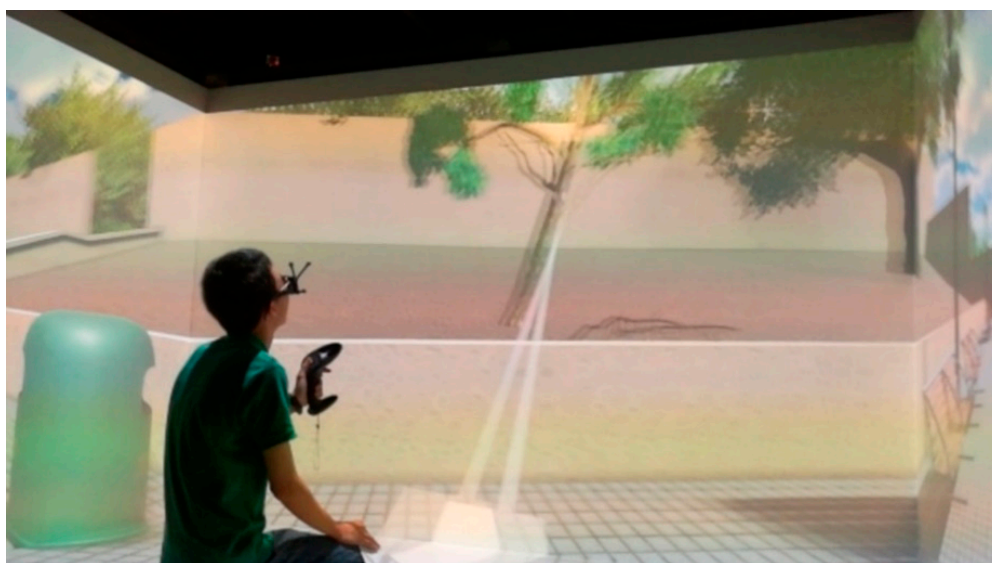


Figure 2. Enablement of first-person presence in the tree pruning simulation with the aid of a head-mounted device that allows 360-degree viewpoint of virtual environments, without physical damage to the ecology of the site, thus ensuring environmental sustainability of this practice.



Figure 3. Tree felling practice in the VLE through the interaction of their avatars and digital objects.

Specific learning content was developed involving two major areas of teaching and learning in horticulture and landscape management. First, interactive tree pruning simulations were devised. By simultaneous responsive graphic projections of the virtual environment, students can learn and practice tree felling, fungus removal, and branch trimming in a simulated environment for a course related to tree risk management (Figure 4). The interactive ARVR learning platform offers a sustainable practice for trial-and-error learning as no real trees and plants will be subject to alterations and damages from the trimming exercises. Virtual training can be practised by multiple cohorts without adverse impact on ecology. Second, the curriculum has placed great emphasis on the development and implementation of the latest concepts and best practices of smart urban forestry. The learning platform facilitates the use of sensors and the Internet of Things (IoT) technologies, as well as open data, particularly through the use of mobile applications (apps), and open-source mapping platforms to monitor techniques to learn about stewardship and empowerment in green space planning. There are specific tasks associated with conceptualising smart urban forest management, as well as case studies to engage students in using sensor networks, big data analytics, robotics and ARVR technologies in horticulture and landscape management practices.



Figure 4. ARVR system that can be implemented in landscape design as a tool for visualisation to review scenarios with real-time reflection effects and references to the simulation.

3.2. Research Methodology

This study aims to test the hypothesis that ARVR educational technology could afford the four distinct learning modes in experiential learning in an environmentally sustainable manner through the synchronous hybrid arrangement of a tree management course. The empirical study collects and analyses student opinions on immersive educational technology by a post-participation survey questionnaire. The research assesses student experience of the ARVR course to give insights into the potential of immersive technology as a viable approach to sustain experimental learning in the new normal. The research first challenges the initial scepticism related to using computer modelling in horticulture education. Some literature criticizes that the initial keen interest coupled with high expectations on ARVR was frequently followed by disillusionment since the high hopes were not satisfied [13]. At times, advanced modelling as a scientific technique has been considered remote from practice, unreliable, or too complicated to use. Gradually, well-developed virtual training, such as some pruning software systems, showed experimental results with a high degree of immersiveness and was able to access the environment data in providing intelligent guidance for pruning decisions [17]. Such technology and training software offer effective technical support for the research and development of horticulture and arboriculture-related curriculum. At the same time, some game-based education systems with the design practice of learning by playing [18] simulated many interesting growth situations with direct feedback from different levels of pruning schemes. There is a gradual maturity in using ARVR in horticulture teaching but most research studies still focus on the technical intervention. Students' attitudes towards its full adoption remain an under-researched area. The COVID restrictions present a rare opportunity for a natural experiment to evaluate the interchangeability of immersive experiential learning and traditional practical training.

The study applies two types of quantitative analysis of the survey responses. First, the descriptive statistics of the survey outcomes illustrate the overall satisfaction rate of the ARVR technology in affording the experiential learning cycle. Second, the research also conducts hypothesis testing to validate the impact of ARVR on different learning modes of an experiential learning cycle. Students were provided with basic background and a three-hour training session on how to use ARVR technology for learning before course attendance. Towards the end of the semester, students were invited to participate voluntarily in the survey questionnaire as part of the course evaluation. The design of the questionnaire was reviewed and approved by the faculty research committee. The survey questionnaires were distributed to the third-year students who had undergone the transition from traditional learning (lectures, tutorials, physical field trips, etc.) to ARVR learning because of the COVID disruptions. The questionnaire contains 27 questions (see Appendix A) that ask participants to evaluate the respective affordances of these two distinct learning formats for the four learning modes as depicted in ELT. The questionnaire takes around 10 to 15 min to finish. A total of 64 valid responses were received. To construct regression on the explanatory variable—participation in ARVR training, the responses are further amplified to two subgroups: (1) group experienced with traditional learning ($N_1 = 64$); and (2) group experienced with innovated ARVR learning ($N_2 = 64$) through mapping of survey questions to response variables (see Appendix B).

Ordinary least squares (OLS) regression was applied to test if virtual experiential learning makes a significant impact on the four distinct learning modes. Participation in the ARVR course is the only independent variable and the four stages of the experiential learning cycle, i.e., concrete experience (CE), reflective observation (RO), abstract conceptualisation (AC) and active experimentation (AE), are modelled as the dependent variables respectively. The generalised regression models are formulated as below:

$$CE_i = c + \beta_i(\text{Participation}) + \varepsilon \quad (1)$$

$$RO_i = c + \beta_i(\text{Participation}) + \varepsilon \quad (2)$$

$$AC_i = c + \beta_i(\text{Participation}) + \varepsilon \quad (3)$$

$$AE_i = c + \beta_i(\text{Participation}) + \varepsilon \quad (4)$$

Participation is a dummy variable, taking one if the person has participated in the ARVR learning sessions and zero otherwise.

CE_i ($i = 1 \dots 3$) represents a positive affirmation of concrete experience, including an authentic learning process, real hands-on experience of tree management and a specific considering factor about whether virtual field trips via ARVR can serve as a cost-effective substitution during the pandemic when traditional field trips are difficult to organise.

RO_i ($i = 1 \dots 3$) indicates signs of reflective observation, such as increased critical thinking, flexible and frequent reflective process, and convenient peer review.

AC_i ($i = 1 \dots 3$) stands for capability of abstract conceptualisation, e.g., participants can generate their own conceptual theories to apply to reality, show a deeper understanding of theory learnt from paper and gain experience to solve real-life problems.

AE_i ($i = 1 \dots 3$) is the last stage of the learning cycle, when participants put learnt concepts from previous stages into practice, plan further activities and test them out.

Values of all the dependent variables are derived from the corresponding five-point Likert scale survey questions (1 = strongly disagree to 5 = strongly agree). The higher scores indicate better performance in each learning stage as per self-evaluation, i.e., the effectiveness of learning, either with the help of ARVR technology or solely by traditional teaching and learning.

β_i are the parameters to be estimated if the null hypothesis can be rejected, i.e., usage of ARVR technology provides a better experience in any of the learning stages than traditional teaching and learning.

4. Results

4.1. Descriptive Statistics

The overall satisfaction level and effectiveness of ARVR technology adoption for each stage of the experiential learning cycle are shown in Table 2 and illustrated graphically in Figure 5.

Table 2. Satisfaction level and effectiveness of innovated ARVR learning for Kolb's experiential learning cycle ($n = 64$).

Stage/Attributes	SA%	A%	Neutral%	DA%	SDA%
Concrete Experience (CE)					
Authentic learning process	25.00	43.75	31.25	0.00	0.00
Real hands-on experience	1.56	56.25	42.19	0.00	0.00
Cost-effective substitution during pandemic	14.06	57.81	28.13	0.00	0.00
Active Experimentation (AE)					
Able to apply theory to practice	35.94	45.31	18.75	0.00	0.00
Planned activities	26.56	34.38	39.06	0.00	0.00
Easy to retry and test	18.75	54.69	26.56	0.00	0.00
Abstract Conceptualisation (AC)					
Generated own conceptual theory to apply to reality	10.94	39.06	37.50	12.50	0.00
Deepened understanding of theory learnt on paper	17.19	54.69	28.13	0.00	0.00
Experience gained for solving real-life problems	12.50	68.75	18.75	0.00	0.00
Reflective Observation (RO)					
Boosted critical thinking	10.94	53.13	25.00	10.94	0.00
Flexible reflective process	20.31	43.75	23.44	1.56	10.94
Convenient peer review	12.50	59.38	18.75	0.00	9.38

SA—strongly agree, A—agree, DA—disagree, SDA—strongly disagree.

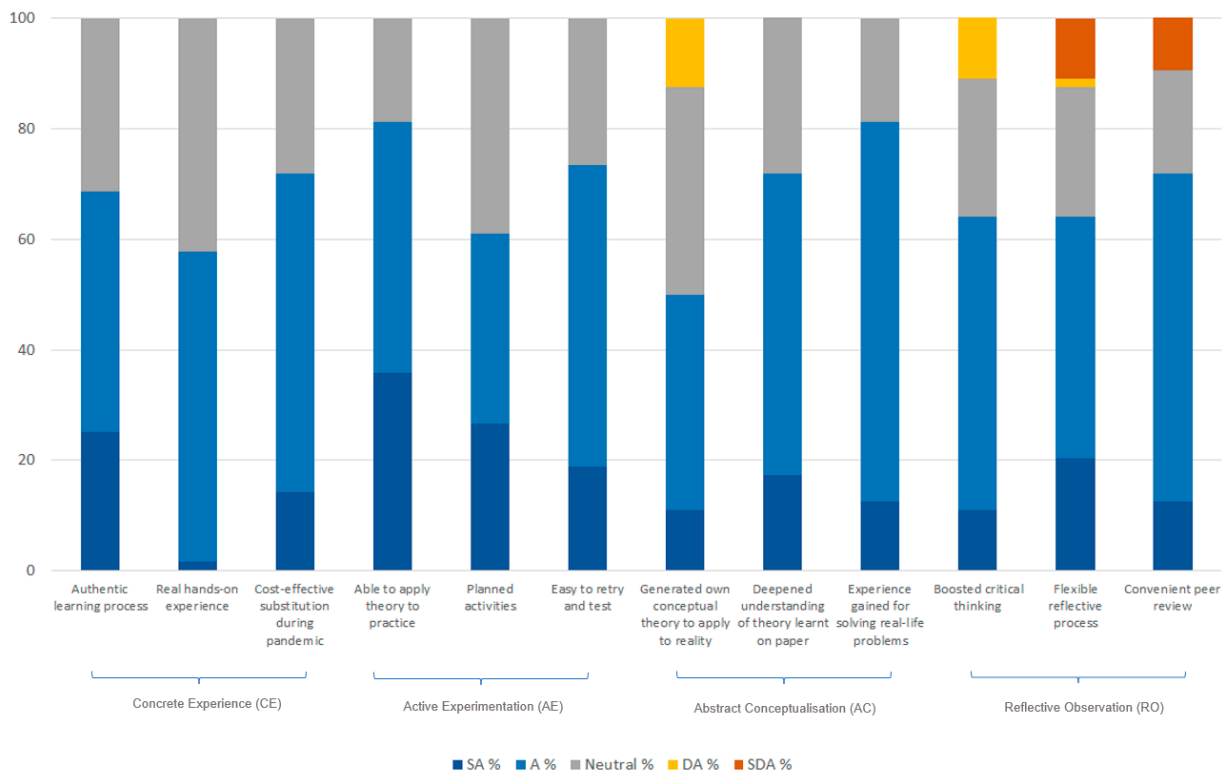


Figure 5. Comparison of student satisfaction level and effectiveness of ARVR learning among different learning modes in experiential learning cycle ($n = 64$).

The adoption of ARVR technology in the renewed course has received a satisfaction rate of over 55% (total % in strongly agree and agree) in every learning mode of the experiential learning cycle. The overall positive feedback provides preliminary evidence to support that immersive technology used in horticulture and landscape management education can improve students' learning experiences. The results show that students agreed that ARVR was particularly capable of affording the learning mode of concrete experience (CE) and active experimentation (AE). All participating students hold a neutral to favourable opinion over the effectiveness of ARVR in these two learning modes. The application of ARVR technology is found to be effective in the delivery of an accessible, cost-effective and well-planned practical learning experience during the pandemic; 71.87% of students who took part in the virtual tree management course give favourable ratings on this attribute. Among all the attributes, ARVR technology has the best performance in supporting students to apply theory into practice (AE) and gain experience in solving real-life problems (AC). However, we observed that there was a non-negligible portion of participants who had negative views over the performance of ARVR in some attributes in the learning modes of reflective observation (RO) and abstract conceptualisation (AC): 12.5% of participating students do not agree that ARVR could facilitate them to generate their own conceptual theory to apply to reality and perceive that ARVR was ineffective in boosting critical thinking; and 9.38% disagree strongly that it could support convenient peer review in the learning process.

The descriptive statistics of explanatory and response variables from the survey responses are presented in Table 3 and the comparison of students' opinions between the two learning formats is illustrated in Figure 6. Upon a comparison of the average opinion between ARVR learning and traditional learning, which constituted mainly face-to-face lectures, tutorials and physical field trips, the latter still has advantages in providing an authentic learning process and real hands-on experience under the concrete experience (CE) learning mode as supported with the higher mean ratings in these two attributes. However, the use of ARVR technology (mean score of 3.86/5) is substantially agreed upon as a

sustainable and cost-effective method of learning and teaching compared with traditional learning during the pandemic (mean score of 2.02/5). On the other hand, the learning mode of active experimentation (AE) has received better feedback with larger mean values of all three attributes under the ARVR format when compared with the traditional learning approach. Students found that they could easily plan and enact ideas into practice in the virtual course. In the renewed programme, experimental activities can take place in controlled VLEs without restrictions on time, space, weather, etc. Students can practice their tree felling and pruning techniques and conduct other experiments on virtual plants without draining the resources of natural environments. Regarding abstract conceptualisation (AC), both learning approaches have similar average ratings. One possible explanation is that knowledge grasping by comprehension in experiential learning would be very much aligned with or without technological interventions. For reflective observation (RO), ARVR has received more favourable ratings than the traditional learning format in two attributes, namely, the improvement in critical thinking and the flexible reflective process. However, one can observe that there is a large standard deviation among participants' responses that is due to the polarisation of students' opinions towards ARVR learning compared to traditional learning. It refers to the phenomenon that even though some participants agree that an ARVR approach is more supportive of the RO learning mode as it enables a more flexible reflective process and helps enhance critical thinking, several students disagree with such claims. The comparison of the average opinions of these two learning approaches reveals that virtual experiential learning has a good potential to bring about an authentic learning experience by allowing students with multiple opportunities to re-do learning practices, deepen their understanding of subject matters and validate their learning outcomes.

Table 3. Descriptive statistics of explanatory and response variables ($N_1 + N_2 = 128$).

Stage/Attributes	Traditional Learning Mean	Traditional Learning S.D.	ARVR Learning Mean	ARVR Learning S.D.	All Mean	All S.D.	Range
Concrete Experience (CE)							
Authentic learning process	4.0469	0.8248	3.9375	0.7533	3.9922	0.7887	1–5
Real hands-on experience	3.8125	0.9739	3.5938	0.5261	3.7031	0.7873	1–5
Cost-effective substitution during pandemic	2.0156	0.9676	3.8594	0.6391	2.9375	1.2344	1–5
Active Experimentation (AE)							
Able to apply theory to practice	3.9375	0.7741	4.1719	0.7249	4.0547	0.7562	1–5
Planned activities	3.6406	0.5154	3.8750	0.8067	3.7578	0.6844	1–5
Easy to retry and test	3.5625	1.0216	3.9219	0.6739	3.7422	0.8806	1–5
Abstract Conceptualisation (AC)							
Generated own conceptual theory to apply to reality	3.3594	0.7636	3.4844	0.8543	3.4219	0.8095	1–5
Deepened understanding of theory learnt on paper	3.7500	0.6667	3.8906	0.6695	3.8203	0.6692	1–5
Experience gained for solving real-life problems	3.9844	0.6783	3.9375	0.5599	3.9609	0.6199	1–5
Reflective Observation (RO)							
Boosted critical thinking	2.4375	0.8333	3.6406	0.8236	3.0391	1.0226	1–5
Flexible reflective process	3.0469	1.2141	3.6094	1.1632	3.3281	1.2174	1–5
Convenient peer review	3.7188	0.7008	3.6563	1.0269	3.6875	0.8762	1–5
Participation							
Participant of ARVR learning	0	0	1	1	0.5	0.502	0–1

Values of each attribute correspond to responses to a survey question, ranging from 1 to 5. Attribute mapping to the survey questions can be found in Appendix B.

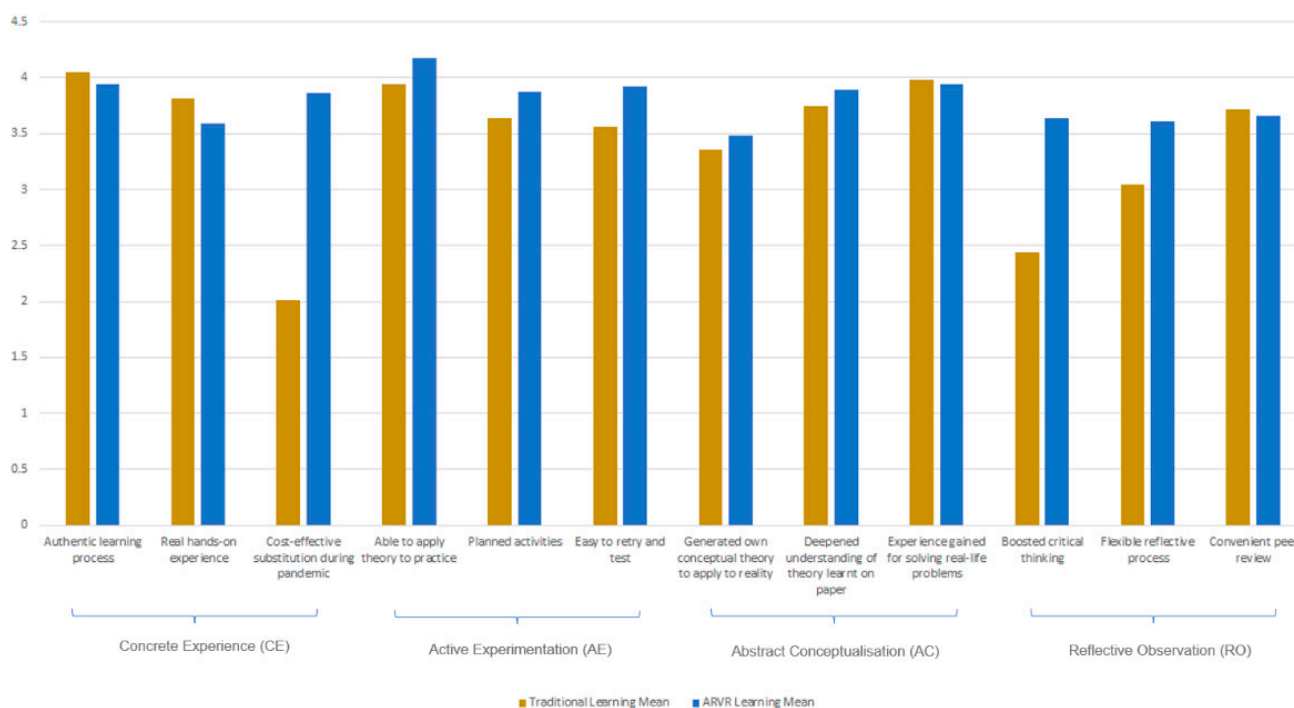


Figure 6. Comparison of average opinion towards traditional and ARVR learning.

4.2. Ordinary Least Squares Regression Models

Table 4 gives the results of the ordinary least square (OLS) regressions on the survey responses, with feedback from students on traditional and ARVR learning formats. Among the four stages of the experiential learning cycle, three of the learning modes, namely, concrete experience (CE), active experimentation (AE), and reflective observation (RO), have at least one attribute model that is statistically significant to reject the null hypothesis. Interpreted with the descriptive statistic, the regression results further demonstrate that ARVR learning sessions receive better feedback on average in these three learning stages than traditional learning.

Table 4. Regression results of generalised models for each response variable.

Stage/Attributes	Coefficient	Std. Error	Adjusted R ²	F-Statistic
Concrete Experience (CE)				
Authentic learning process	−0.1094	0.1396	−0.0031	0.6136
Real hands-on experience	−0.2188	0.1384	0.0117	2.4996
Cost-effective substitution during pandemic	1.8438 ***	0.1450	0.5587	161.7875
Active Experimentation (AE)				
Able to apply theory to practice	0.2343 *	0.1326	0.0165	3.1257
Planned activities	0.2344 **	0.1197	0.0218	3.8363
Easy to retry and test	0.3594 *	0.1530	0.0344	5.5186
Abstract Conceptualisation (AC)				
Generated own conceptual theory to apply to reality	0.1250	0.1432	−0.0019	0.7616
Deepened understanding of theory learnt on paper	0.1406	0.1181	0.0033	1.4179
Experience gained for solving real-life problems	−0.0469	0.1099	−0.0065	0.1818
Reflective Observation (RO)				
Boosted critical thinking	1.2031 ***	0.1465	0.3436	67.4846
Flexible reflective process	0.5625 ***	0.2102	0.0463	7.1634
Convenient peer review	−0.0625	0.1554	−0.0066	0.1617

* p < 0.10. ** p < 0.05. *** p < 0.01.

Concrete Experience: Although the descriptive statistic in the previous section indicates that traditional learning received a slightly better response to the ARVR format in the first two attributes of CE, no statistically significant difference between their effectiveness is found according to the regression results. However, the regression of the last attribute of CE shows that learning with ARVR is more sustainable, cost-effective and flexible during the pandemic in students' perception as its F-statistic is significant at a 1% significance level. The adjusted R^2 value of the OLS regression model of this single attribute has explained 55.9% of such variance. In the aspect of CE learning mode, the performance of ARVR is closely matched with traditional learning but proved to be superior during the pandemic.

Active Experimentation: The regression models show ARVR has better affordance of the learning mode of active experimentation (AE) compared with traditional learning as all three attributes are with a statistically significant positive coefficient respectively. Therefore, ARVR consistently outperforms traditional learning in AE as it provides a convenient venue for the enactment of new ideas and planned experiments.

Abstract Conceptualisation: There is no significant statistical correlation found between ARVR learning and any attributes of abstract conceptualisation (AC), therefore the null hypothesis cannot be rejected. The regression provides no evidence to support the claim that ARVR learning is more effective than traditional learning in this aspect, albeit the descriptive statistic shows it has a weak advantage.

Reflective Observation: The regression model shows that ARVR learning has positive relationships with the two attributes of RO, including the facilitation of critical thinking and promotion of a flexible reflective process at a 1% significance level. There is no statistically significant correlation between ARVR learning with the attribute of convenient peer review. Overall, the statistical evidence indicates that the use of immersive technology in experiential learning can effectively enhance the RO learning mode with results that outmatched traditional learning.

5. Discussion

The statistical analysis shows that the use of immersive technology in a deliberately designed hybrid learning course could pedagogically afford all four learning modes of experiential learning. In contrast to most immersive VR studies that focus on the tangible offerings of learning experience through resemblance to real-life scenarios with fidelity simulations, this research provides statistical evidence that immersive technology could boost higher-order cognitive learning and purposeful action. The descriptive and regression results of this research show that the new technology could bring about a significant positive impact on knowledge transformation by facilitating the learning modes of reflective observation (RO) and active experimentation (AE) and attain comparable effectiveness in knowledge grasping (CE and AC) of traditional learning.

The study substantiates that the use of ARVR could ease student enactment of explorative activities such as laboratory testing and virtual practical training (CE and AE). Its substantial boost to critical thinking and iterative reflection during the learning process expands our understanding of the pedagogical affordance of immersive technology. The ARVR's significant positive impact on RO could be explained by the complex interconnectivity of the learning modes in Kolb's theory. In ELT, experiential learning involves two interdependent adaptation strategies, which include the grasp of knowledge (by concrete experience and abstract conceptualisation) and the transformation of knowledge (by reflective observation and active experimentation) [11]. Learning is optimal and sustainable when learners activate these learning modes in balance. Using ARVR offers a convenient digital learning space where students can repeat and revisit their learning tasks in a most controlled virtual environment at their discretion. They can practise their skills, validate their understanding of newly gained knowledge, and test concepts under different assumptions with the flexibility offered by the virtual learning platform. Such enablement brings about an enhancement in CE and AE aspects, but also provides more opportunities for eliciting RO activities. Improvement in CE and AE aspects elevates students' perfor-

mance in RO by reciprocally reinforcing the cyclical learning process. Moreover, easy switching among different learning modes under virtual experiential learning supports students' iterative reflections flexibly, which also could result in the enhancement of the RO learning stage.

Albeit the favourable average opinion in higher-order learning including the RO and AC modes, a minor portion of students held opposing views. They expressed that immersive technology itself had little value in enhancing higher-order cognition. Although they agreed that ARVR made the learning experience more engaging, they also criticised that the intensive course structured with high visual impact fidelity graphical content held them back from cognitive thinking as they could not sufficiently concentrate on reflecting and assimilating the content knowledge. Their survey results and the adverse comments revealed that students have different levels of acceptance of the extensive use of ARVR in teaching and learning, which may be due to a mismatch of their preferential learning styles [53] or extra cognitive load resulting from cybersickness during the immersion [54].

6. Conclusions

The COVID pandemic has sped up the adoption of immersive educational technologies in higher education, which resulted in some environmental innovations. Rapid technological development has transformed traditional pedagogy into a multimodal operation, where technology becomes an integral entrance to learning and teaching [55]. This paper offers a strategy to implement a hybrid arrangement of synchronous hybrid team-based learning that used to rely heavily on practical fieldwork. The innovation allows the resumption of in-person education in a hybrid setting. Educators and students can switch formats between the traditional classroom and online courses flexibly according to the latest COVID restrictions and personal preferences over social isolation during the pandemic. The findings of this research show that students welcomed the use of immersive technology in experiential learning, which has enhanced the sustainability of a horticulture programme. In the long term, extended reality can become a powerful pedagogical tool to create learning environments that can afford the ever-changing needs of today's education, especially when some of our natural environments are under threat. As a post-pandemic teaching tool, ARVR immersive technology offers a digitally connected virtual learning space which successfully mimics real-life situations to offer an engaging experiential learning experience without damaging the real habitat. This research confirms that ARVR can facilitate synchronous hybrid team-based learning in the most environmentally conscious manner. Moreover, immersive technology provides a viable means to expand class size with new engagement strategies without potential environmental damage to physical landscape ecologies. The implementation of the ARVR technology has greatly improved the sustainability and resilience of the course.

This study recognised that digital experimental learning could retain most benefits of training in real situations and improve the sustainability of the teaching approach. One major limitation of this study is that we cannot directly compare the learning outcomes of traditional learning and ARVR learning as it would be unethical and discriminating by providing different teaching treatments to students out of research purpose. By comparing student opinions of two teaching methods under the natural experiment of the abrupt shift from traditional learning to digital learning during the pandemic, this study provides preliminary evidence that affirms the potential of extended reality to sustain quality education without sacrificing the essential aspects of experiential learning and can be seen as a sustainable learning tool to encourage virtual dialogic collaboration, online engagement and interactive hybrid learning. While education practitioners are enthusiastic about the wide adoption of new technology to make learning and teaching more sustainable, future research should focus on addressing the frustration and difficulties encountered during the transition and establish principles to guide the curriculum design and implementation of immersive learning programmes.

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Informed Consent Statement: Informed consent was obtained from all students involved in the study.

Data Availability Statement: The survey data that support the findings of this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

A questionnaire survey on a five-point Likert scale on students’ perception of virtual experiential learning.

Please Answer These Questions					
	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1. ARVR offers authentic learning experience to the understanding of the subject.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2. I can gain same authentic learning experience to the understanding of the subject in traditional learning.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3. ARVR makes me feel like the real tree felling/pruning/trimming.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4. I can have same experience of real tree felling/pruning/trimming in traditional learning.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5. ARVR allows me to apply learnt theory into practice.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. I can apply learnt theory into practice in traditional learning.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7. ARVR smoothly acts as I planned the activities.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8. I can plan my activities in real life as in ARVR smoothly.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9. ARVR allows me to retry and test out my assumption easily.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10. I can retry and test out assumption in real life as in ARVR easily.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11. The conceptualization of the landscape theory can be applied to the ARVR.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12. I can apply the conceptualization of the landscape theory to real life easily with traditional learning.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13. After the operation of the VR, I have deeper understanding of the landscape theory learnt on paper.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14. I can have deep understanding of the landscape theory by simply reading from paper.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15. I have gained experience from operation of ARVR and feel more confident to solve real-life problems.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16. I can gain same experience from traditional learning and feel confident to solve real-life problems.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17. Aside from the operation of the AR, the activity allows me to think critically.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18. I am able to have same level of critical thinking with traditional learning.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19. ARVR encourages more frequent reflective thinking, as I can redo, revise, and review my progress with no constraints of time/space/venue etc.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20. I am able to have reflective thinking, redo, revise and review my progress without any constraint easily in traditional learning.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21. ARVR allows my peers to observe my action and make peer review judgements and I can learn from each other.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22. My peers can observe my action and make peer review easily in traditional learning.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23. ARVR offers a cost-effective method to mimic real life tree felling, which is an efficient method used for future learning during pandemic.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24. Traditional field trips are costly and hard to organize during pandemic.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25. ARVR provides a sustainable method of learning and teaching during pandemic.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26. ARVR is cost-effective means to develop teaching and learning materials.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
27. ARVR has high demand on IT support and equipment requirements.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Appendix B

Mapping of survey questions to response variables in the regression models.

Stage/Attributes	Traditional Learning	ARVR Learning
<i>Concrete Experience (CE)</i>		
Authentic learning process	Question 2	Question 1
Real hands-on experience	Question 4	Question 3
Cost-effective substitution during pandemic	Question 24	Question 23
<i>Active Experimentation (AE)</i>		
Able to apply theory to practice	Question 6	Question 5
Planned activities	Question 8	Question 7
Easy to retry and test	Question 10	Question 9
<i>Abstract Conceptualisation (AC)</i>		
Generated own conceptual theory to apply to reality	Question 12	Question 11
Deepened understanding of theory learnt on paper	Question 14	Question 13
Experience gained for solving real-life problems	Question 16	Question 15
<i>Reflective Observation (RO)</i>		
Boosted critical thinking	Question 18	Question 17
Flexible reflective process	Question 20	Question 19
Convenient peer review	Question 22	Question 21

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