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An empirical study on immersive technology in synchronous hybrid learning in design education

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Abstract
Immersive technology plays an increasingly important role in design education, supporting digital literacy and experiential learning in higher education, particularly in the post-COVID-19 context. Many design disciplines, such as Architecture and Landscape Design, which used to rely heavily on physical field trips, and dialogic studios as signature pedagogies, had to adapt to the proliferation of innovative educational technologies due to the suspension of face-to-face teaching and learning. Augmented reality and virtual reality are now extensively used in technology and design education to support a more interactive, collaborative, and student-centred approach to learning. This paper expands on a pilot research study on the transition from traditional signature pedagogies of studio-based design education to technology-enhanced collaborative learning to support experiential learning. Based on Kolb's experiential learning framework concerning four learning modes, namely, concrete experience (CE), reflective observation (RO), abstract conceptualisation (AC), and active experimentation (AE), this paper analyses data from 75 undergraduate students across four cohorts in three different higher education institutions in Hong Kong. They were surveyed on their experiences of synchronous hybrid virtual experiential learning with design and technology curricula. Furthermore, six students were interviewed about their experiences. The research findings confirm two research hypotheses showing that immersive experiential learning could constructively align RO and AE, thus bringing an overall positive impact on the experiential learning process, but shows no conclusive influence on promoting CE, especially AC. The quantitative findings and qualitative results gave new insights into the discussion of the theoretical and practical implications of the study.

Keywords Immersive technology · Technology and design education · Architecture and design · Experiential learning · Higher education

Introduction

The COVID-19 pandemic has drastically disrupted face-to-face teaching and learning (T&L) in higher education in most parts of the world. Many higher education institutes have expedited the implementation of digitalisation for a rapid transition to online teaching,

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triggering new forms of interactive and collaborative technology-driven ecosystems (Kang, 2021). The pandemic not only catalysed the emergence and popularity of information and communication technology (ICT), but also further propelled more development in technology and design education, keeping up with the demands of the rapidly evolving post-digital learning.

The conceptualisation of technology in design education can be grounded in four main categories of interest: technology as artefacts, as knowledge, as activities, and as volition in knowing how to use technology (Mitcham, 1994). At the same time, new modalities of hybrid virtual learning and emerging educational technologies present enormous opportunities to liberate T&L from the spatial and temporal constraints associated with traditional classrooms (Bozkurt & Sharma, 2021; Lee et al., 2022), and to greatly transform curriculum development, assessment and impacts on our contemporary society. With the increased accessibility of ICT applications in educational settings, knowledge inquiry is no longer restricted to formal learning environments such as lecture theatres and laboratories on the physical campus.

Students can acquire knowledge and digital literacy in any informal environment with the advantage of interactive affordances of new technologies (Amilyana et al., 2021; Fonseca & Conde, 2018; Thorne & Hellermann, 2022). Technology and design education encourages learners to acquire proficiency in the creation and manipulation of digital designs and the utilisation of multimedia to bring learning concepts to fruition. As a result, the scope of design education has broadened, fostering a deeper integration with constructivist learning theories related to design thinking concepts such as ideation, reflection, and critiquing (Öztürk, 2021; Stables & Buck, 2021). Other implicit values associated are collaboration, creativity, empathy, iteration and problem-solving which are unique signature pedagogies for design education (McLain, 2022; Shulman, 2005).

The digital evolution in design education has facilitated the acquisition of diverse knowledge not only in the conceptual and theoretical development for STEM education (Gorman & Conley, 2019), but also in enhancing visualisation, inductive reasoning, memory, and intelligence (Buckley et al., 2018). In addition, the incorporation of blended educational approaches, such as hybrid learning, HyFlex, and dual-mode teaching bridges onsite and online learning, and promises unprecedented flexibility in both synchronous and asynchronous learning settings (Raes et al., 2022). The enhancements of digital technologies such as online T&L systems, digital gamification, flipped classroom methods, robotics, massive open online courses (MOOCs), and augmented virtual reality (ARVR) enhance students' participation, class engagement, and collaborative interaction (Fidalgo-Blanco et al., 2018; Fonseca et al., 2018). Across the spectrum of immersive technology, augmented reality (AR) and virtual reality (VR) are now increasingly blended to support the provision of a more comprehensive and engaging curriculum across different disciplines (Gerup et al., 2020; Guo et al., 2021; Lee & Hwang, 2022; Maas & Hughes, 2020; Smith et al., 2021).

ARVR has not only gained significant momentum in technology and design education, but has also become an imperative asset in design-based learning (Camba et al., 2017; Chemerys et al., 2021; Horvat et al., 2022), understanding digital technology in design (Xu et al., 2022), and experiential learning in ways to enhance the experiences between natural and artificial, non-living and living matter, matter and mind, virtual and real, etc. (Jones et al., 2013). The applications of ARVR in design education open new T&L opportunities to enable a fully immersive, open, creative, collaborative, and dialogic construction of knowledge (Sanfilippo et al., 2022).

Although the pedagogical benefits of immersive learning environments are evident in collaborative learning (Russell, 2019), there is still limited research examining the relationship between immersive technology and experiential learning paradigms, and the discourse on a hybrid approach to design education remains insufficient (Barry, 2022; Freina & Ott, 2015). This paper aims to fill the research gap by exploring how students perceive the efficacy and effectiveness of immersive experiential learning in design education in Hong Kong based on Kolb's (1984) experiential learning theory (ELT).

Using a mix of qualitative and quantitative methodologies, this research employs a questionnaire survey and focus group interviews to examine learners' user experience and scrutinise how they perceive the impact of immersive educational technology on the four experiential learning modes, namely, active experimentation (AE), reflective observation (RO), concrete experience (CE), and abstract conceptualisation (AC) (Kolb, 1984).

Specifically, this research investigates the implementation of immersive technology in design education through the lenses of 1) curricular development, 2) hybrid approach in T&L, 3) learning performance, 4) student motivation, and 5) feedback and assessment. Drawing upon Kolb's (1984) experiential learning framework, the paper contributes to a more comprehensive understanding of the potential of immersive technology in diverse design educational contexts. The research spans from the COVID-19 pandemic to the post-pandemic period. It is based on a pilot study of immersive technology in education programmes in the context of synchronous learning (Lamb et al., 2022). The participants were seventy-five undergraduate students who have experienced and reflected on the four stages of experiential learning. Contrary to conventional design education in lectures, students were involved in the co-creation of the learning content with a specific focus on synchronous design education drawing the theocratic framework (de Vries, 2005) highlighting 1) the collaboration in the design of technology artefacts; 2) development of discipline-specific knowledge; 3) creation of T&L activities to enhance students' motivation; and 4) reflection on the learning performance and impacts on humanity, society, and culture.

This study seeks to explore the impact of immersive technology on the actual experiential learning that has been traditionally gained through physical site visits in design education. This study seeks to contribute to a deeper understanding of the adaptation of immersive technology in a synchronous hybrid context and the changing landscape of design education in the post-digital age.

The paradigm shift of signature pedagogies in technology and design education

The classic literature of Shulman (2005) identifies the signature pedagogies of various disciplines, drawing the characteristic forms of T&L as a discursive framework for technology and design education in three fundamental phases of activities of ideating (designing), realising (making), and critiquing (evaluating) (McLain, 2022; Shulman, 2005). Some unique signature pedagogies, including studio learning, critique sessions, and field trips, are highly valued in several disciplines of design education, such as in the focus of this paper in Architecture, Product Design, Landscape Design, Horticulture and Landscape Management, and Tree Management programmes. These study areas are mostly concerned with authentic design work revolving around the built form and organic outdoor environments as extensions of physical buildings with considerations of human activities and functions (Duzenli et al., 2017).

Although most of these design disciplines support learning environments in studios, laboratories, workshops, and ateliers (DiGiano et al., 2009), there is also a significant component that is embedded with applied knowledge and cognitive learning through interactive and physical engagement with the natural outdoor environments. While experiential learning is integral to the disciplines, it has been significantly impeded by restrictions imposed during the COVID-19 pandemic (Ummihusna & Zairul, 2022). Take Landscape Architecture as an example, its traditional signature pedagogies were dominant with didactics on understanding the vegetal landscape in geographical areas through physical interactions and the knowledge transfer to future professionals through design innovations (O'Neill & Hung, 2010). COVID-19 disruption has invoked the evolution of these signature pedagogies in both their conditions (e.g., forms and environments of practice) and technologies (e.g., affordances facilitated by new tools and techniques) (McLain, 2022). Despite the gradual return to on-campus learning for students, many tertiary institutions predict that faculty development programmes and design courses will continue to include a mix of online and hybrid options. To integrate the expanded curricular content and address the emergence of synchronous hybrid teaching, the design curriculum has to devise new pedagogical approaches to incorporate synchronous hybrid digital learning to diversify design literacy, implement more design thinking, and synthesise academic knowledge with industry demands (Monacella & Keane, 2022) with a focus on interactional affordances for seamless physical-virtual group collaboration and improved teacher facilitation. Many traditional T&L activities based on a design studio model evolved rapidly to respond to broadening and intensifying changes in environmental, social, and political conditions. These changing conditions require innovation that extends the core design competencies where learners have to deal with complex contemporary issues (Monacella & Keane, 2022). As a result, curricula design has undergone vigorous reorganisation to embrace more practical approaches to address learners' holistic twenty-first-century competencies (Deighton et al., 2023).

Some technology and design education relies heavily on hands-on activities, such as field trips, site visits and excursions to achieve learning objectives, design educators have adopted alternative means to sustain the T&L with hybrid modalities. Under the paradigm shift, new instructional design involves the navigation of synchronous learning environments to engage learners cognitively (Hattie, 2012; Raes, 2022), by integrating collaborative problem-solving skills (Roschelle et al., 2010), to embrace digitalisation for improved flexibility, and making T&L less dependent on time and location constraints (Lakhal et al., 2017). One obvious advantage provided by the use of immersive simulations in design education is to involve teaching and learning without geographical and seasonal limitations. Take Landscape Design education as an example, the use of digital simulations allows virtual learning in different ecologically-sensitive contexts, thus saving tremendous travelling time and costs. Virtual field trips, which couple with experiential components and technology-enhanced learning, allow students to visualise their design outcomes in a hybrid approach and receive instant feedback, without waiting for months to years for their experimental cultivars to grow, or exposure to physical site dangers or risky environments in the process (Kee & Zhang, 2022). There is ample evidence to support the practical benefits of synchronous virtual learning. First, synchronous immersive learning allows students to train in a safe environment while avoiding real-life dangers, while maintaining learners' curiosity and enthusiasm with more student motivation compared to conventional methods (Alrehaili & Al Osman, 2022; Green et al., 2014). Immersive technology overcomes particular difficulties associated with experiential learning to mitigate significant risks (Bliss et al., 1997) or raise ethical concerns (Ota et al., 1995) in real-life. A key attribute of educational technology is that it allows students to explore, experience and experiment with design curricula without geographical restraints (Fung et al., 2019) and beyond the bounds of physical possibility (Johnston et al., 2018). Secondly, the use of immersive technology supports the sensory-motor paradigm by Kolb and Fry (1975) to promote the cognitive process in a constructivist approach, greatly improving learning performance and students' motivation (Asad et al., 2022). Hamilton et al. (2021) suggest that there are interactive applications between immersive technology content and practical learning in alignment with learning outcomes and student motivation. Several studies suggest that immersive technology interventions could improve learners' motivation and engagement (Allcoat & Mühlenen, 2018; Bos et al., 2019) and such effects were more pronounced if the learning modules were designed with a game-based approach (Pellas et al., 2019; Shi et al., 2022) or with features to enable social interactions (Bouta et al., 2012). The switch to hybrid learning has catalysed the adaptation of immersive technology as an artefact in object-based learning and student-centred learning. The rapid adoption of immersive technology to sustain signature design education has elicited the reconceptualisation of learning spaces. New formats of learning environments, such as virtual simulated learning environments, cave-based immersive learning environments, and Metaverse, have emerged rapidly in different e-learning platforms (Cheung et al., 2021; de Back et al., 2021) that are essential in design education. The proliferation of computer simulation technology in automotive design facilitates new infrastructure and pedagogies to draw on the synergy between the "imbrication of human and material agencies" (Leonardi, 2011, p.147) to offer a more dialogic, collaborative, and team-based design curriculum. Therefore, this imbrication metaphor is used to suggest how a human agency approach to technology can usefully incorporate notions of material agency into its explanations of organisational change to signify a paradigm shift in the performance of traditional pedagogies in design education which has long emphasised physical field studies or studio with the enhancement of synchronous immersive T&L.

Aside from the enhancements on behavioural cognitive and affective aspects through the enablement of first-person immersion and development of comprehensive competency, design students also move away from instructor-led activities to self-directed learning as they can explore resources and processes autonomously to achieve learning goals, which are no longer defined by teachers but set by themselves in immersive experiential learning (Sanfilippo et al., 2022). Nesenbergs et al. (2020) have reviewed the use of immersive technology in distance learning in higher education with supporting evidence on the positive impact on student engagement in promoting practical, spatial and kinaesthetic skills acquisition. Their study aligns with our argument that interactive technology enhances design education in content planning, student motivation, feedback, and interactivity. While immersive learning earns great momentum in design education, it is not without criticism when it comes to practice. Insufficiency of proper-developed digital content, poorly designed software and hardware, underfunding of technology support, and lack of long-term planning are common issues hindering wider usage of immersive technology in design education (Domingo & Bradley, 2018; Jensen & Konradsen, 2018; Krajčovič et al., 2021). More importantly, the pedagogical focus should be on the overall organisation and presentation of the T&L content, and ensuring sufficient institutional and technical support (Caserman et al., 2021; LaViola, 2000; Mareta et al., 2022; Sharples et al., 2008) because these are all key elements to impact students' performance, design tasks, and authentic learning experience.

Kolb's experiential learning theory (ELT)

Kolb's Experiential Learning Theory (ELT) is a well-established pedagogical framework which can serve as the pedagogical foundation for designing and developing educational experiences. Drawn from theories by Dewey, Piaget and Lewin, Kolb's ELT articulates a mechanism of learning and development, where knowledge is created through experience (Kolb, 1984). The theory enunciates learning as an iterative process encompassing perceptual apprehension and cognitive comprehension of real-life experience. The dynamic process involves the "*dual dialectics of action/reflection and experience/abstraction*" (Kolb, 1984), which entails four confronting modes of learning (Fig. 1):

Concrete Experience (CE) examines how learners encounter direct experience by completely involving themselves in a situation without bias. Learners actively engage by performing a task or solving a problem in a situated context.

Reflective Observation (RO) suggests that learners must reflect on and observe their experiences introspectively and make meanings from their observations, thoughts, and feelings.

Abstract Conceptualisation (AC) is when learners integrate their observations and create new concepts with logically coherent theories at this stage. It involves reflection, which focuses on resolving conflicts and tensions, and gives rise to new ideas and modification of existing abstract concepts.

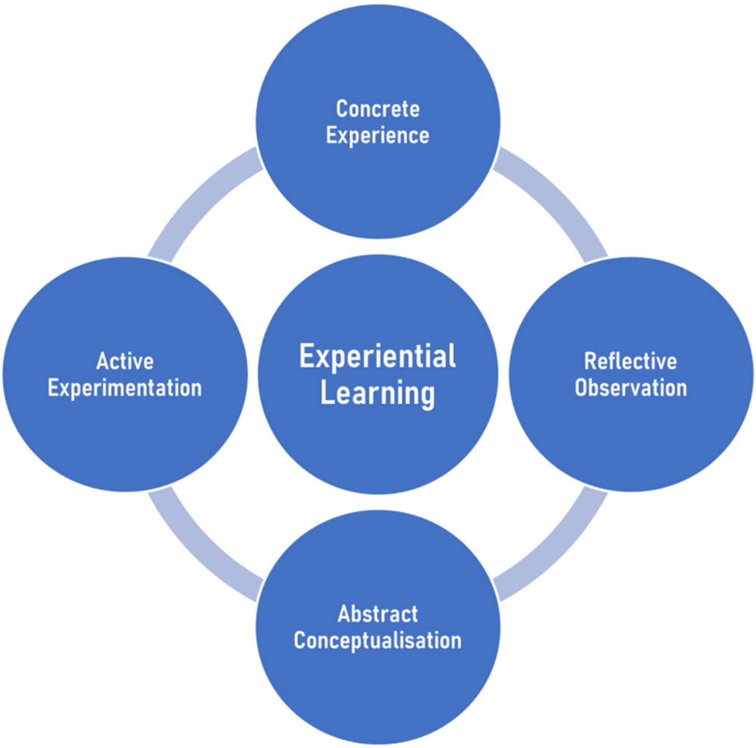

Fig. 1 Kolb's Experiential Learning Cycle (Adapted from Kolb, 1984)

Active Experimentation (AE) looks at how learners validate their newly created concepts by applying ideas to problem-solving or decision-making. The experimentation also results in new concrete experiences and restarts another interlinked cycle of learning (Korucu-Kış, 2021).

Kolb's framework provides a suitable framework for the current study in the specific context of design education because it places life experiences as a critical part of the process wherein "knowledge is created through the transformation of experience" (Kolb, 2015, p. 49). It differs from behavioural learning theories which focus on stimulus and response, and provides short shrift to student reflection and agency. Kolb's experiential learning theory has been fruitfully applied to many different fields of study including management, psychology, information science, medicine, nursing, accounting, and law among others (Kolb, 2015; Morris, 2020).

Despite many empirical studies demonstrating the potential of immersive experiential learning in different technology and design education (Cha et al., 2012; Chang et al., 2023; Concannon et al., 2019; Fung et al., 2019; Liu & Butzlaff, 2021), the knowledge transformation remains controversial (Bossard et al., 2008; Loke, 2015). The preliminary evidence affirms the phenomenon that immersive educational technology focuses vastly on the enablement of *doing* (CE and AE) but without a meaningful answer for the facilitation of *thinking* (RO and AC) (Kee & Zhang, 2022). Moreover, across several studies on student perception of virtual learning, even though students generally held favourable views of applying immersive experiential learning in design education, they rejected it as an interchangeable way for real-life training, and opined that its deployment should be of auxiliary only (Abdulwahed & Nagy, 2009; Baxter & Hainey, 2019; Makransky et al., 2021). Overall, the design and development of a content-rich yet virtual experiential learning curriculum remains a conundrum for academics given the lack of sound theoretical underpinnings and established good principles and practices (Fowler, 2015; Mikropoulos & Natsis, 2011; Radianti et al., 2020; Wang & Burton, 2013).

Development of hybrid experiential learning

In the discourse of technology and design education with the development of technological capability, five types of knowledge have been identified: declarative knowledge; conceptual knowledge; procedural knowledge; conditional knowledge; and casual knowledge (Buckley et al., 2019a, 2019b). Although knowledge and skills are separate entities, they are interactive. It is observed that technological capability describes the unison of skills, values, and problem-solving in a three-set Venn diagram underpinned by conceptual knowledge (Buckley et al., 2019a, 2019b; Gibson & Harris, 2008). While the relations of skills, values and problem-solving are grounded in the theory of knowledge as artefacts, knowledge, activities, and humanity (de Vries, 2005), the research explains the interventions in detail created by the interdisciplinary cohorts of undergraduate students and their teachers in four separate programmes in three higher education institutions in Hong Kong. The co-design process for this study involves multiple stages. Firstly, T&L content was conceptualised in four academic semesters from 2018 to 2021 through a collaborative problem-based learning (PBL) project between three higher education institutions, including a self-financing tertiary education institute, a University Grants Committee-funded university, and a vocational training institute in Hong Kong. At the planning stage, teachers and students co-designed the T&L course design by utilising technology as an artefact to engage in collaborative experiential learning. The cohorts of students formed a cross-disciplinary team to identify key problems related to the development of digital learning materials in their existing design curricula. The learning content and activities had to address several tree-falling accidents during that period in Hong Kong. In particular, the resulting high casualties had already prompted public concerns and triggered the government to revamp existing tree management policies to mitigate the threat of tree planting in the hyper-dense urban context of Hong Kong. The course co-design process consisted of T&L concept inception, instructional design, learning activities, rubrics, feedback and assessment stages. The cross-disciplinary team was composed of teachers with design backgrounds and students with technological skills. The knowledge would be driven from pedagogy, supported by technology to benefit not only academic use, but also the greater community and the government. The process was contextually driven, ensuring the knowledge utilised design thinking, digital literacy, and integrating design theory into practice. The format of delivery would be synchronous hybrid learning as the pandemic has given rise to the opportunity to revamp post-digital class orchestration and engagement strategies. Since design education in higher education sees the global influence of collaborative online international learning (COIL) (Vahed & Rodriguez, 2021), synchronous hybrid learning can blur geographical boundaries in contemporary T&L. Secondly, the design team defined the PBL activities utilising immersive technology as the artefacts to generate disciplinary knowledge. With more development in education technology (Buck-Sorlin & Delaire, 2013) and increasing access to immersive systems (Renganayagalu et al., 2021), synchronous hybrid T&L activities become the supplement to traditional teaching (Atkins et al., 1996; Weber & Penn, 1995; Wu et al., 2019; Xia et al., 2009) to embrace knowledge related to humanity. The co-create project spanning the semesters helped develop better knowledge in discipline-specific content, skills in communication and group collaboration to enhance experiential learning, and its process of developing knowledge as *artefacts, knowledge, activities, and humanity* would be tested by the mixed method analysis.

Research methodology

Approach

This study is rooted mainly in Kolb's (1984) ELT. However, it also draws on other established frameworks as theoretical underpinnings. Ummihusna and Zairul's (2022) qualitative evaluation was considered appropriate because it offers insight into the positive cognitive outcomes derived from the use of immersive learning technology by interpreting participants' textual records. Feng et al. (2018) and Lin and Hsu(2017) have shed light on the interpretation of the participants' textual records on student's design works; and how interviews were used by means of understanding participants' sharing and comparing experiences as a result of immersive technology intervention (Maghool et al., 2018). Jones et al. (2013) focused on how the developing field of technology education has played a role in teaching, learning and assessment, while the mix method approach proposed by Asad et al. (2022) has given a framework for measuring immersive technology as a pedagogical tool showing enhancement in experiential learning. The implementation followed several stages.

Compliance with ethical approval

The team recruited participants from all four institutions and course coordinators, and obtained informed consent from students in writing for participating in the questionnaire survey and interviews. Participants were informed about the study's purpose, procedures, and confidentiality before obtaining their informed consent. The team administered the questionnaire survey to all participants in multiple semesters. The invited participants were divided into two groups, one using immersive educational technology and the other using traditional teaching methods to explicitly demonstrate the difference in learning modalities and impact. All participants' data in the survey and interviews were anonymized from the beginning since no signifiers were used.

Post-participation survey questionnaire

This research has built upon the pilot research by Kee and Zhang (2022), with a post-participation survey questionnaire to examine the effectiveness of immersive educational technology by comparing the new hybrid learning with the traditional one, where little or no technology had been used. Immersive learning has been heavily used in higher education disciplines such as information technology and engineering (Rizov & Rizova, 2015) but this paper offers an alternative perspective in technology and design education. Since research on students' learning in design education in Hong Kong remains an under-researched area, this study probes into its potential in the paradigm of experiential learning from the student's perspective. A pilot study was conducted with multiple cohorts of third and fourth-year undergraduates from selected disciplines in the technology and design education programmes between 2018 and 2019 (Kee & Zhang, 2022). Students who participated in the earlier pilot study appraised that the application in a hybrid setting could help bridge the gap between in-person education and conventional online learning. This study was expanded to include other cohorts from two local institutions in the subsequent semesters. Drawing reference to Huang and Hew's goal-access-feedback-challenge-collaboration design model (Huang & Hew, 2021; Bai et al., 2022), the pilot study gave insight into the effectiveness of students' learning and task completion. The control group studied the conventional course without intervention, whereas the other group was exposed to the immersive T&L interventions.

Focus group interviews

Focus group interviews were conducted during the pre-intervention, mid-term, and post-intervention periods to better understand the roles of course co-design and the impact of immersive technology in relationship with experiential learning. The contents of the focus group interviews were video-recorded and transcribed. The qualitative data were compared and cross-referenced using thematic analysis. The questionnaire survey was designed based on taught courses with references to Kolb's experiential learning framework. Students were also asked about the user-experience, sustainability and other fundamental perceptions from a learner's perspective. In the focus group, conversations were based on students' learning experience, comparison with traditional pedagogical approaches and their perception towards Kolb's model. Students were encouraged to share their personal learning experiences, challenges, preferences, and aspired learning scenarios. They were asked about their opinions and experiences on virtual experiential learning, for example, "Is synchronous immersive technology a sustainable approach in learning course materials?" to generate a deeper understanding of their perspectives. Researchers would clarify the questions and moderate the interview process when interviewees looked confused, unassertive or hesitated. Given the open-ended questions in nature, the focus group allowed group discussion of a small group of 6 participants. The participants entered the research study voluntarily and were free to withdraw from the study at any time without any penalty.

Co-designing hybrid T&L content

The interdisciplinary team worked to reform the design courses with new immersive technology as knowledge artefacts to implement interactive T&L in existing design education. Key knowledge content with a particular focus to address knowledge related to humanity issues. Incorporating Kolb's ELT, the curriculum has scaffolded three pillars in theoretical foundations, experiential learning activities and iterative critical reflections (Fig. 2). The content was also cross-checked with inputs drawn from both academics and industry experts. Based on the design principles of the virtual learning environment (VLE) (Dalgarno & Lee, 2010), the focus on an immersive learning environment was to reconstruct the learning scenarios with enhanced fidelity by incorporating local features of the geography in the visual, spatial, and audio aspects. The interactive media design was based on the research on local wisdom and protocols (Chau et al., 2020; Hui et al., 2020; Jim & Zhang, 2015; Lee et al., 2019, 2021) with the incorporation of T&L

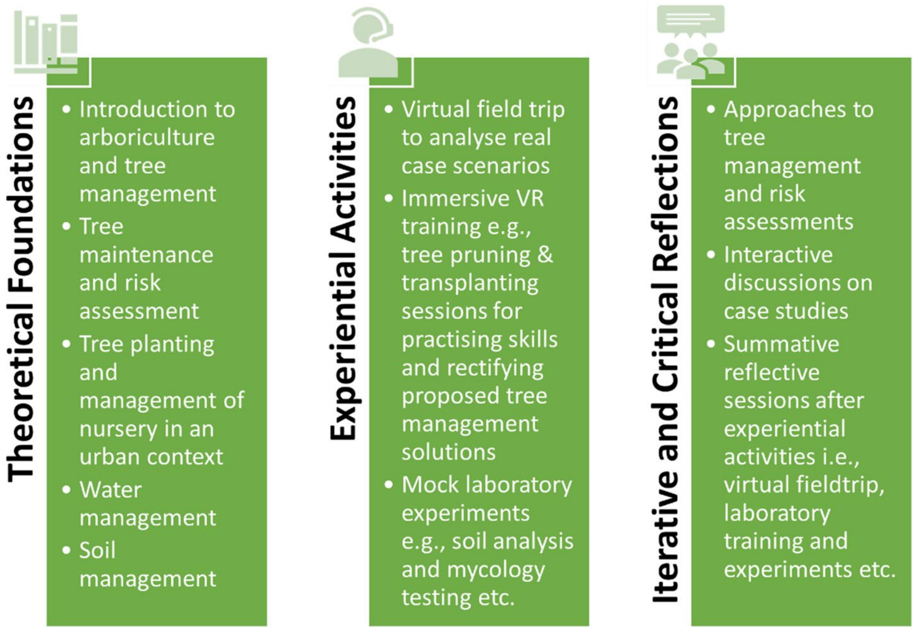

Fig. 2 The curriculum structure of the synchronous hybrid team-based experiential scaffolded with particular immersive learning in the design education in Landscape Design

Fig. 3 Students and teachers co-designed an immersive experiential learning experience, where T&L artefacts, discipline knowledge and hybrid interactive activities were developed to address key social issues concerning humanity-related phenomena

activities to enhance learning performance and student motivation (Fig. 3). In particular, kinaesthetic learning supported by contextual and vision-haptic visualisation were incorporated into the knowledge driven by the T&L activities. The team co-created the T&L artefacts, and class activities to generate discipline knowledge related to humanity as the main content of the course development (Fig. 4). The design of the hybrid learning facilitated the interaction between the online and physical learners, allowing a seamless synchronous learning environment. The cohorts were involved in peer feedback and the rubric design where assignments and peer-assessment mechanisms were discussed and co-planned in the process.

Fig. 4 Simulated interactions with visualised embodiments of actions help students better comprehend the underlying theories and concepts, by which student engagement and motivation are enhanced

Data collection

Quantitative data

To evaluate the effectiveness of virtual experiential learning, data was collected from third- and fourth-year students of the selected technology and design disciplines. Upon completing the three-month design modules by synchronous hybrid learning, students were asked to complete a survey to evaluate the immersive technology experience in relation to experiential learning in a student evaluation. The survey instrument was designed based on Kolb's experiential learning theory and adapted from the previous research study on students' perceptions of virtual experiential learning (Kee & Zhang, 2022). The questionnaire includes 27 statements operationalised with a five-point Likert Scale, ranging from "Strongly Disagree" (1) to "Strongly Agree" (5). The questionnaire takes around 10 min to complete. The first 24 questions included statements about students' perceptions of ARVR learning versus traditional learning. These questions compared immersive technology use and traditional learning, arranged in an alternate matching format, thus prompting students to directly compare with traditional learning and rate their performance in supporting the four different learning modes as described in Kolb's experiential learning cycle, i.e., concrete experience (CE), reflective observation (RO), abstract conceptualisation (AC), and active experimentation (AE). In addition, the survey also asked students to evaluate the sustainability of synchronous immersive learning during the pandemic, its cost-effectiveness, and the demand for IT support and equipment.

A total of seventy-five students participated in the questionnaire survey. Students completed the questionnaire voluntarily and anonymously with informed consent. The survey outcome illustrates the overall satisfaction rate of immersive technology in facilitating experiential learning in the technology and design modules. Secondly, the research constructed hypotheses to analyse if participation in hybrid T&L activities can provide a similar, or an enhanced learning experience, in comparison to traditional learning where traditional learning was adopted. This research seeks to test the

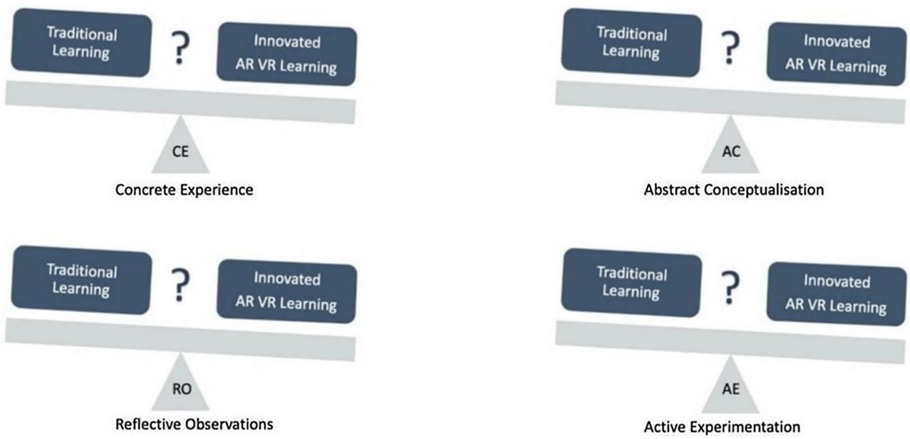

Fig. 5 Hypothesis Testing: Effectiveness of traditional pedagogy vs. ARVR technology using Kolb's experiential learning cycle

hypothesis that immersive learning is an appropriate T&L approach for reflective observation (RO) and abstract conceptualisation (AC) to take place. The hypotheses are illustrated in Fig. 5 below.

To test the hypotheses, ordinary least squares (OLS) regression was conducted to examine if students perceived that conducting experiential learning in VLEs has a significant influence on the learning outcomes versus traditional learning. *Participation* in the new technology modules is the only independent variable in the OLS regression models. The dummy variable takes one for the new immersive technology learning and zero for traditional learning. The four learning modes of Kolb's experiential learning cycle are modelled as four dependent variables i.e., CE, RO_i, AC and AE_i respectively. The regression models were formulated as equations below:

$$\text{Concrete Experience}: \quad CE_i = c + \beta(Participation) + \varepsilon$$

$$\text{Reflective Observation}: \quad RO_i = c + \beta_i(Participation) + \varepsilon$$

$$\text{Abstract Conceptualisation}: \quad AC_i = c + \beta_i(Participation) + \varepsilon$$

$$\text{Active Experimentation}: \quad AE_i = c + \beta(Participation) + \varepsilon$$

CE_i (i = 1…3) characterises a positive confirmation of concrete experience, epitomising the authentic learning process and attainment of practical experience from experiential learning activities. It also includes a specific factor determining the substitutability of virtual field trips via immersive technology during the pandemic when physical learning such as field trips was not feasible under public health measures.

RO_i (i = 1…3) denotes the facilitation of reflective observation, which includes enhanced critical thinking, a flexible reflective process, and convenient peer review.

AC_i (i = 1…3) concerns whether the learning format is capable of supporting students' abstract conceptualisation by assisting them to transform the learning experience into conceptual theories and apply them to solve real-world problems.

AE_i (i = 1…3) refers to the active experimentation learning mode, when students put developed concepts from the abstract conceptualisation stage into action and validate them via conducting experimental tasks or projects.

The values of these dependent variables are determined from respective sets of questions in the five-point Likert scale survey. The higher ratings represent a better performance in the concerned learning modes. To test the null hypothesis, parameters β_i are estimated. A significant positive value of β_i indicates that the use of technology could better afford the respective learning modes.

Qualitative data

The targeted sample of six students from the third- and fourth-year student cohorts were invited to participate in the focus group interview. These participants were recruited with a multimodal approach through invitation emails and person-to-person interactions. The interview was conducted with a semi-structured interview guide. The content of the interviews was recorded during the pre-intervention, mid-term, and post-intervention periods to reflect on the prior knowledge level and perception of the use of the immersive technology as an online participation and a physical participant to compare the experience of the synchronous hybrid approach. The interview questions were developed by the research team and reviewed by the Human Research Ethics Committee for ensuring validity. Based on the feedback, the interview guide was revised for the interview conduction process. In total, six interviewees having the same ratio of male and female participants were conducted. Before the interview process, participants were provided with informed consent and all the ethical considerations. The interviews were audio-recorded, transcribed, coded, and analysed by thematic analysis on the three foci: 1) effectiveness of the hybrid approach in T&L, 2) learning performance and student motivation, and 3) feedback and assessment. The emerged themes were then discussed and reviewed. At last, those themes were made constructs for the confirmed responses on the use of synchronous immersive technology in relationship with experiential learning.

Table 1 Satisfaction level and affordances of ARVR learning for Kolb's experiential learning cycle (N = 75)

Stage/attribute	SA %	A %	Neutral %	DA %	SDA %
Affordances for learning modes in the experiential learning cycle					
Concrete experience (CE)					
Authentic learning process	25.33	42.67	32.00	0.00	0.00
Real hands-on experience	1.33	56.00	42.67	0.00	0.00
Cost-effective substitution during the pandemic	14.67	57.33	28.00	0.00	0.00
Reflective Observation (RO)					
Boosted critical thinking	12.00	52.00	25.33	10.67	0.00
Flexible reflective process	21.33	41.33	25.33	1.33	10.67
Convenient peer review	13.33	57.33	20.00	0.00	9.33
Abstract conceptualisation (AC)					
Generated own conceptual theory to apply to reality	12.00	38.67	37.33	12.00	0.00
Deepened understanding of theory learnt on paper	17.33	54.67	28.00	0.00	0.00
Experience gained in solving real-life problems	12.00	69.33	18.67	0.00	0.00
Active experimentation (AE)					
Able to apply theory to practice	34.67	46.67	18.67	0.00	0.00
Planned activities	26.67	33.33	40.00	0.00	0.00
Easy to retry and test	20.00	53.33	26.67	0.00	0.00
Other attributes					
Sustainability during the pandemic	40.00	37.33	22.67	0.00	0.00
Cost-effectiveness	26.67	52.00	20.00	1.33	0.00
Demands on IT support and equipment	62.67	13.33	22.67	1.33	0.00

SA Strongly agree, *A* Agree, *DA* Disagree, *SDA* Strongly disagree

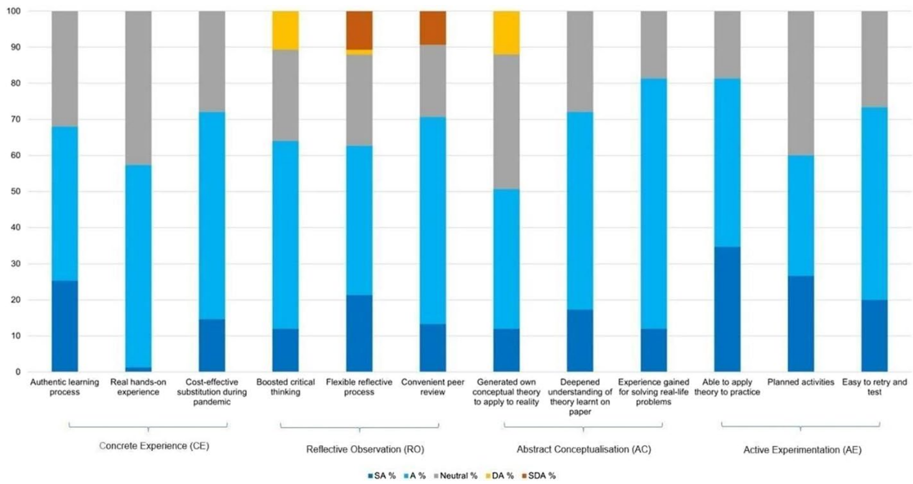

Fig. 6 Student satisfaction level of using immersive technology learning among the four learning modes described in Kolb's experiential learning cycle (N = 75)

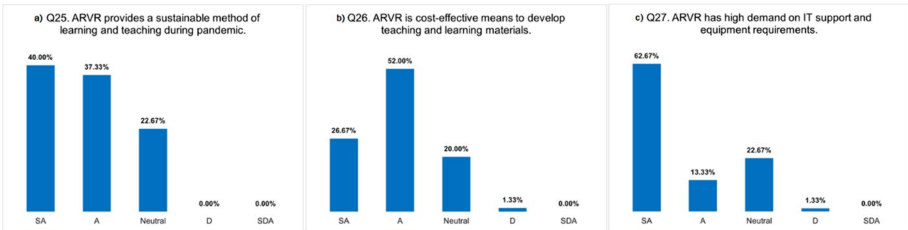

Fig. 7 Students' opinion on other attributes of immersive technology learning: **a** its sustainability during the pandemic (Q25), **b** its cost-effectiveness (Q26), and **c** whether it is demanding on IT resources (Q27) (N = 75)

Results

Data and descriptive statistics

Overall effectiveness and satisfaction of technology adoption in design education

Before comparing to the traditional learning format, the overall satisfaction level of immersive technology learning is shown in Table 1, which encapsulates students' perceived effectiveness of the use of technology in terms of the learning modes of Kolb's learning cycle and the other three attributes regarding its sustainability and implementation: a) the sustainability of synchronous hybrid immersive learning during the pandemic (Q25), b) its cost-effectiveness (Q26), and c) whether it is demanding on IT resources (N = 75). The results are also illustrated in Figs. 6 and Fig. 7, respectively. In general, the technology-driven experiential learning module received over 50% satisfaction rate (SA% + A%) in every stage of Kolb's experiential learning cycle. All respondents gave neutral or positive ratings of the effectiveness of immersive technology in CE and AE learning modes. The results showed that immersive learning could enable experiential learning, where students gained experience through performing learning activities in a digital space. This reaffirms the well-known advantages of immersive technology in the delivery of learning-by-doing experiences in VLEs. Among the sub-factors constituting the affordance for the four learning modes, the innovated ARVR technology excelled most in allowing students to rehearse and gain experience to solve real-life problems (under AC) and enabling them to apply theory to practise (under AE), with 81.33% of the respondents acknowledging these benefits. However, it is observed that a small portion of participants (12%) see obvious limitations and ineffectiveness of ARVR technology in certain attributes of reflective observation (RO) and abstract conceptualisation (AC). It is worth noting that 12% of respondents object that technology-driven experiential learning could help them generate their own conceptual theory to apply to reality; over 10% of respondents perceive that immersive technology is ineffective in boosting critical thinking and enabling a flexible reflective process; 9.33% of respondents strongly disagree that it can support convenient peer review simultaneously.

Aside from the experiential learning modes, students were also asked to indicate to what extent they agree with the three statements concerning if immersive technology is a sustainable T&L approach during the pandemic (Question 25) and regarding its perspective of long-term development and further implementation in the course curriculum in design education (Question 26 & 27). All respondents agree that ARVR provides a viable method to sustain learning during the pandemic (40% strongly agree, 37.33% agree, and 22.67% are neutral). On one hand, students perceived that ARVR should be cost-effective to develop T&L materials (26.67% strongly agree and 52% agree with the statement). On the other hand, they also acknowledged that the new technology has a high demand for IT support and equipment requirements (62.67% strongly agree and 13.33% agree with the statement).

The reliability of a questionnaire, which pertains to the consistency of the survey results, is an essential aspect to consider in this research. Given that measurement errors can be present in content sampling, assessing the consistency of a questionnaire via its internal consistency is crucial. Internal consistency is generally estimated using coefficient alpha—Cronbach's alpha. In practice, Cronbach's alpha value of at least 0.7 serves as an indication of adequate internal consistency. The Cronbach's alpha of this questionnaire is 0.935, with a 95% confidence interval of [0.912, 0.955], indicating an excellent internal consistency.

A common method to examine the response bias and the limitation of a questionnaire is to check the appearance of extreme response styles among the collected answers. An extreme response style refers to the tendency of respondents to give extreme answers in a questionnaire. In total 18 answers with extreme response style in this questionnaire, among which 8 survey respondents chose 'Neither agree or disagree' for all of the questions, 9 survey respondents chose 'Agree' for all of the questions, 1 survey respondent chose 'Strongly agree' for all of the questions.

Comparison of affordance of immersive technology learning versus traditional learning for experiential learning

The descriptive statistics of the explanatory and response variables of the OLS models (N = 150) are outlined in Table 2 and illustrated in Fig. 8. From the statistics, traditional learning, which entails classroom lectures, slightly outperforms immersive technology learning in facilitating authentic learning and providing students with real hands-on experience. However, under the COVID-19 restrictions which seriously derailed in-person learning arrangements, students acknowledge the potential of using immersive technology to

Table 2 Descriptive statistics of explanatory and response variables (N = 150)

Stage/attribute	Traditional learning		ARVR learning		All		Range
	Mean	S.D	Mean	S.D	Mean	S.D	
Concrete experience (CE)							
Authentic learning process	4.0533	0.8433	3.9333	0.7593	3.9933	0.7931	1–5
Real hands-on experience	3.8267	0.9619	3.5867	0.5223	3.7067	0.7417	1–5
Cost-effective substitution during the pandemic	2.0133	0.9690	3.8667	0.6438	2.9400	1.1946	1–5
Reflective observation (RO)							
Boosted critical thinking	3.5600	0.8228	3.6533	0.8301	3.6067	0.8261	1–5
Flexible reflective process	3.0533	1.2324	3.6133	1.1612	3.3333	1.2223	1–5
Convenient peer review	3.7200	0.6957	3.6533	1.0331	3.6867	0.9059	1–5
Abstract conceptualisation (AC)							
Generated own conceptual theory to apply to reality	3.3467	0.7789	3.5067	0.8601	3.4267	0.8294	1–5
Deepened understanding of theory learnt on paper	3.7333	0.6549	3.8933	0.6693	3.8133	0.6653	1–5
Experience gained in solving real-life problems	3.9867	0.6648	3.9333	0.5534	3.9600	0.6000	1–5
Active experimentation (AE)							
Able to apply theory to practice	3.9333	0.7808	4.1600	0.7174	4.0467	0.7503	1–5
Planned activities	3.6400	0.5347	3.8667	0.8110	3.7533	0.7209	1–5
Easy to retry and test	3.5600	1.0664	3.9333	0.6844	3.7467	0.8916	1–5
Participation							
Participant in 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. The mapping of attributes to corresponding survey questions and the arrangement of alternate matching can be found in the pilot study conducted by Kee and Zhang (2022)

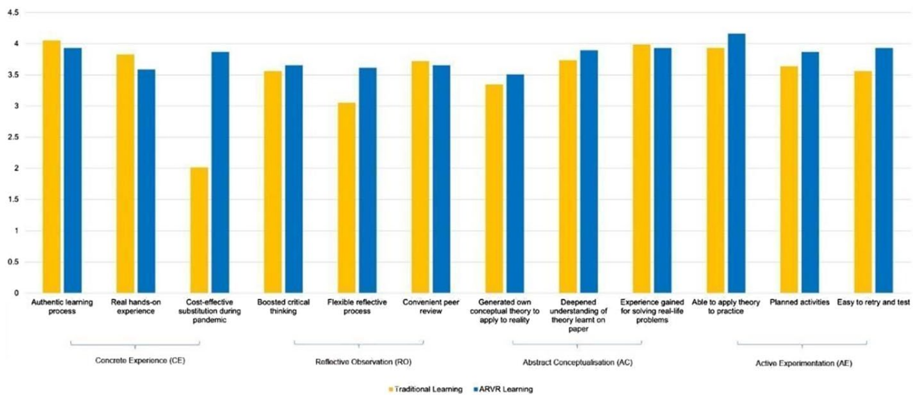

Fig. 8 Comparison of students' average opinion toward traditional and immersive technology learning (N = 150)

help with the cost-effective adaptation of the design pedagogies. They give a significantly higher rating of 3.87 to ARVR learning versus 2.01 to traditional learning in this CE sub-attribute. Regarding RO, ARVR has comparable performance with traditional learning and gives a strikingly positive performance in supporting a flexible reflective process. At the same time, it can be observed that these sub-attributes under immersive technology learning show a large standard deviation when compared to traditional learning, which means more students hold extremely different views between these two learning formats, either pros or cons. Regarding abstract conceptualisation, traditional learning and immersive learning have similar average ratings. There is not much contradiction or revelation as the abstract conceptualisation in experiential learning has little differentiation between these two learning formats. Finally, immersive technology learning has received better feedback than traditional learning in all three sub-attributes of AE. As the nature of technology, all experimental activities can happen in a controlled manner, but without the restrictions of time, space, and weather. Students can easily retry and actively apply the theory to practise in the virtual learning space. Overall, these statistics highlight the potential of immersive technology in design education. The comparable ratings among attributes reveal critical findings that virtual experiential learning has great potential in a synchronous hybrid setting with particular learning performance, instant feedback and design-based learning.

Results of ordinary least squares regression models

Table 3 presents the OLS regressions on the survey responses. Out of the four learning modes of Kolb's experiential learning cycle, three of the modes (CE, RO & AE) have at least one attribute with a statistically significant relationship with the independent variable i.e., *Participation* in the new immersive technology incorporated into the design modules. The regression results confirm our observations from the descriptive statistics, where ARVR learning

Table 3 Regression results of generalised modules for each response variable

Stage/attribute	Coefficient	Std. Error	Adjusted R^2	F-statistic
Authentic learning process	−0.12	0.0913	−0.0009	0.8644
Real hands-on experience	−0.2400*	0.1266	0.0171	3.5946
Cost-effective substitution during the pandemic	1.8533***	0.134	0.5609	191.297
Reflective observation (RO)				
Boosted critical thinking	0.0933	0.1352	−0.0035	0.4765
Flexible reflective process	0.5600***	0.1934	0.0472	8.3849
Convenient peer review	−0.0667	0.1446	−0.0053	0.2124
Abstract conceptualisation (AC)				
Generated own conceptual theory to apply to reality	0.16	0.1313	0.0032	1.4841
Deepened understanding of theory learnt on paper	0.16	0.1089	0.0077	2.1588
Experience gained in solving real-life problems	−0.0533	0.1019	−0.0049	0.2738
Active experimentation (AE)				
Able to apply theory to practice	0.2267*	0.1206	0.0167	3.5314
Planned activities	0.2267**	0.1123	0.0202	4.0766
Easy to retry and test	0.3733***	0.1428	0.0377	6.8367

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

outpaces traditional learning substantially in the attribute of facilitating a flexible reflective process in RO and all three attributes in AE.

Concrete experience From the regression, there is no statistically significant difference between the affordances of ARVR learning and traditional learning in providing an authentic learning experience. However, traditional learning still has its advantages in the delivery of a real hands-on experience. Immersive technology learning shows a negative correlation with a p-value of 0.10 in this attribute. This also aligns with results from descriptive statistics where traditional learning has slightly better feedback than ARVR learning. In terms of cost-effectiveness and sustainability of the learning experience, ARVR learning is perceived to be superior to traditional learning during the pandemic. The regression model has explained 56.09% of such variance, according to the adjusted R^2 value.

Reflective observation The regression model shows that immersive technology has a positive correlation with one of the RO attributes—providing a flexible reflective process, at a 1% significant level. One possible explanation for this positive impact is that immersive technology provides students with the flexibility to redo learning and experiential activities and revisit their work history. For students who are willing to reflect on post-tangible learning stages, such as concrete experience and active experimentation with the help of technology, they can revisit the learning activities at their discretion, as immersive technology provides a more convenient way for students to re-experience their doings. Thus, better supporting their reflections in the RO stage. For peer-review or peer-assessment results, immersive technology does not show a statistically significant advantage over traditional learning, which may be due to the inadequate support provided by the immersive technology learning platform and its operating equipment. Although the technological platform of the renewed module enabled communications among teams and their members, face-to-face communication that takes place in a classroom setting may offer significant value in the peer-review or peer-assessment process.

Abstract conceptualisation None of the 3 attributes of AC has a statistical correlation with immersive technology learning. As Kolb's abstract conceptualisation involves students' personal understanding of the subject, it varies from person to person and the evaluation is more subjective. Statistically, the null hypothesis cannot be rejected. Therefore, the study found no evidence suggesting immersive technology is more effective than traditional learning in supporting the AC stage of the experiential learning cycle.

Active experimentation The results from OLS regression show that immersive technology learning has advantages over traditional learning in active experimentation, with statistically significant positive coefficients of all three attributes. Therefore, we can conclude that immersive technology learning consistently outperforms traditional learning in active experimentation. Among all 3 attributes of AE, immersive technology is best known for its advantage in providing a controlled environment for learning activities and hence can better facilitate the experimental process.

Findings and discussions

To further flesh out the quantitative findings, we delve into the qualitative results. Our qualitative findings demonstrate that synchronous digital experiential learning can become a sustainable T&L approach, which facilitates hybrid team-based learning in higher education. This paper discusses the following revelations about the adoption of immersive technologies with specific foci on the implementation of immersive technology in design education through the lenses of (1) curricular development, (2) hybrid approach in T&L, (3) learning performance, and (4) student motivation, and (5) feedback and assessment.

Concrete Experience is learning by doing. Many educational scholars conceive of concrete experience as a process in which learners are immersed in learning situations that contain much contextual information (Pipitone & Raghavan, 2017). Students generally agreed there is an authentic learning experience embedded in the activities. In the VLEs enabled by extended reality technologies, visual graphic simulations can sufficiently mimic the phenomenon of tree felling in risk management scenarios. Students agree that immersive technology in the design curriculum enables their participation in experiential learning activities, where they acquire hands-on experience and practical knowledge to solve real-world problems.

Learning from observing others is integral to how humans learn (Bandura, 1971). Experiential learning in a virtual environment has the potential to become more enriching when it can sufficiently support the organic interactions among participants. Students applauded that the design modules offered an enjoyable learning experience as they could validate their learnt knowledge and test new concepts conveniently by interacting with the designed artefacts. Most agreed that the experience enhances their learning experience, especially in the active experimentation stage in a synchronous manner. Despite the advantages of enabling students to test their newly acquired knowledge in a controlled and safe environment, an interviewee shared that the immersive learning environments with pre-defined assumptions and carefully planned workflows supported their exploratory experiments, where ideas underlying their epistemic adventure are likely to emerge in trials:

> My learning experience has bridged the gap for the need for practices in controlled virtual environments and expansion of skill sets and diversified my understanding of the challenges in physical environments. Exploring such volatile environments makes my learning experience special.

Other qualitative results demonstrated that synchronous digital experiential learning was considered a sustainable T&L approach, which facilitates hybrid team-based learning in design education:

> The experience of co-design with my teachers gave me a deeper understanding of the discipline. Immersive technology could enable us to be more involved in the curriculum planning and assessment scheme. I *was empowered to design an e-learning environment with greater involvement and understanding of the concepts being taught. This opportunity gave me a more meaningful and fulfilling learning experience, as I could apply knowledge and skills to make an impact to future fellow classmates.*

Alongside the intended learning outcomes, students also appraised the integration of hybrid immersive technology in relationship with their mastery of digital literacy and learning performance. Students commented that participating in synchronous learning has helped them to be flexible in learning at any location not confined to classroom settings. The experience enhances learning performance and motivation in a specific manner:

> The project using the synchronous learning approach helped me develop more knowledge in a hybrid setting which could be collaborative with multiple modalities. I find that what I have learnt is literacy which will help me in the future. For the personal comprehensive competency, in my opinion, I have gained a deep understanding of critical thinking, communication skills and creative thinking as the tools that helped me formulate something which otherwise, I had no access to or was difficult to access.
> I love the convenience and flexibility offered by synchronous hybrid learning

Students agreed that they were able to participate actively in instructional design, curriculum development, feedback, assessment and rubric setting, and these were hands-on practical knowledge they could incorporate into future learning attributes.

Our findings demonstrate that synchronous digital experiential learning can become a sustainable T&L approach, which facilitates hybrid team-based learning in a flexible manner. However, there are limitations to this research as well. Some students prefer the traditional tactile features associated with physical fieldwork which makes design learning a unique learning experience. Students who showed a strong preference for traditional teaching did not agree that immersive technology could substitute for real-life training. They expressed that doing training in real-life is essential to their learning. One possible explanation was that students required physical experience, which enabled them to make essential mapping and establish the effective linkage between the virtual experience and real-world applications. Although the statistics showed that the applications of synchronous technology in design education enabled the flexible reflective process, some students expressed that teaching with extended reality adds little value to critical thinking. They commented that its efficacy in supporting the reflective knowledge process depended on how it was utilised to content knowledge more engagingly. Some students opined that the generalisation of knowledge and formation of abstract concepts required intermittent cool-off pauses, where they could "join the dots" of the diverse topics and phenomena demonstrated and taught in the curriculum. They commented that the intensive structure and the high visual impact graphics of the immersive learning modules held them back from the cognitive process sometimes.

These findings are actually in line with the notions of cognitive load theory which recognizes that humans have a limited capacity for taking in and storing information (Sweller et al., 2019). Cognitive load refers to the load placed on human memory by different cognitive and thinking processes including comprehension, meaning-making and problem-solving among others. Hence, in the educational setting, it emphasises the importance of reducing students' cognitive load by reducing distracting information. Though visual information is usually conceived of as helpful, research on cognitive load theory showed that too much visual information could be problematic. In cognitive load theory, these distracting details are called the "seductive details" effect and have been found to undermine learning (Multu-Bayraktar et al., 2019). The qualitative results seem to confirm this finding as the students complained about the high visual impact of the modules.

In summary, the empirical results of this study showed that immersive technologies could significantly improve the learning experience in a pedagogical sense. The survey results showed that participants held an overall favourable view of how technologies support experiential learning. Students perceived that immersive technology used in design courses is effective in providing a plannable and cost-effective learning experience on course co-design, students' performance and motivation through collaboration and flexibility in the synchronous hybrid mode during the pandemic. Our finding shows that the application of ARVR technologies brings a positive impact on the active experimentation (AE) and reflective observation (RO) modes of learning in the experiential learning cycle, but conclusive evidence on the influence on concrete experience (CE) and especially the abstract conceptualisation (AC) is still lacking.

Limitations and directions for future research

Despite applying a mixed method to integrate the quantitative and qualitative data in the analysis, this study has a few limitations. One of the limitations is the use of self-reported data. Although self-report data has been found to be largely reliable and valid in educational research (Boon-Falleur et al., 2022) and strongly correlated with actual learning gains (Richardson, 2004), future studies may want to triangulate the data with objective assessments of learning. In this study, we complemented the quantitative findings with qualitative interviews. Future studies may want to further triangulate it with how self-reports correlate with authentic and objective assessments so that actual learning performance can be measured.

The second limitation of our study was the sample size and geographical scope. Though our sample size was adequate for the purposes of this study, we recommend future researchers recruit larger samples for both the quantitative and qualitative parts of the study. Furthermore, we recommend future researchers test the theoretical ideas in other cultural contexts aside from Hong Kong.

Conclusion

The paper aims to explore the impact of immersive technology in design education in the context of experiential learning in Hong Kong. With a particular focus on the use of immersive technology, quantitative and qualitative analysis of the findings on the four elements of Kolb's ELT, three critical themes emerged: (1) more participation, interacting with peers and enhanced students' motivation through immersive technology; (2) more instant feedback while design-based learning activities and tasks in the synchronous learning as compared to traditional signature pedagogies; and (3) freedom of both spatial and technological flexibility in a synchronous hybrid mode. By using digital pedagogies in design education, students could engage in experiential learning theory by applying digital literacy to develop creativity, critical thinking, and problem-solving skills in the co-design stages of the learning materials. The iterative and interactive nature of digital pedagogies embraces digitalisation and offers opportunities for improving interaction, collaboration, and flexibility in T&L. However, the study also divulges several challenges in substantiating these benefits, such as the need for well-thought-out content, the demand for easier equity in access to technology, and the avoidance of cognitive overload in the digital environment (Matsika & Zhou, 2021).

Based on Kolb's framework, experiential learning is a holistic process which embraces four mutually supported learning modes. This research offers a perception of the pedagogical affordance of immersive technology from a student-centred perspective. Our recommendation would be to incorporate immersive technologies in the design curriculum to enhance the AE and RO. These modes are critical in the experiential learning cycle as they involve hands-on activities and reflection on the experience, which are essential for building skills and knowledge.

However, we also recommend that instructors supplement the technologies with other learning activities to support CE and AC. These modes involve real-world experiences and conceptualization of abstract concepts, which may not be fully captured by the use of immersive technologies alone. Perhaps one reason for the lack of conclusive evidence on abstract conceptualization (AC) is that this mode of learning is typically harder to generate among students and needs to be actively cultivated (Tanner, 2012). Abstraction does not happen naturally, and teachers need to consciously cultivate it among students and design teaching–learning activities and assessments that promote and facilitate metacognitive reflection and abstraction. Indeed, studies have shown that teachers need to use specific teaching techniques and adopt certain behaviours to cultivate abstraction and metacognition among their students (Karlen et al., 2023; Kyriakides et al., 2020). Moreover, the use of technologies in teaching design education during the pandemic has demonstrated its effectiveness in providing a plannable and cost-effective learning experience. We recommend that instructors continue to incorporate technologies in their teaching to supplement and enhance the learning experience. The COVID-19 restrictions during the pandemic have elicited the rapid adoption of immersive technology in design education. Most students see the opportunity as a good substitute for traditional learning when face-to-face teaching and physical movement are prohibited. However, the approach does have its limitations and shortcomings. Unleashing the potential of digital technologies in transforming traditional educational practices calls for integrating new modalities and creating a unique ecosystem of educational services by engaging new actors and channelling new resources to sustain its momentum. Besides, despite the enthusiasm among students and teachers to embrace the new modalities of digital learning, educational practitioners often struggle with how to design and implement these technological interventions effectively with solid pedagogical foundations. The digitalisation of a curriculum is much more than a direct migration of its content to the digital platform; curriculum courses and resources must be reorganised and restructured to fit different digital means of experiential learning without compromising the signature characteristics of the discipline. In general, teachers and students should be provided with ample training, support and time to familiarise themselves with the new learning modalities. Finally, practitioners should identify diverse pre-implementation training needs of students and intervene early to ensure a smooth transition. Students of different learning styles and demographical, social, economic and cultural backgrounds may significantly differ in readiness and acceptance of these new educational technologies. More studies could be conducted to identify the characteristics of learners who need further support and devise strategies and resources to help them cope with the initial barriers.

Appendix I: Quantitative survey questionnaire

A questionnaire survey on a five-point Likert scale reviewing 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	☐	☐	☐	☐	☐
2. I can gain same authentic learning experience to the understanding of the subject in traditional learning	☐	☐	☐	☐	☐
3. ARVR makes me feel like the real tree felling/pruning/trimming	☐	☐	☐	☐	☐
4. I can have same experience of real tree felling/pruning/trimming in traditional learning	☐	☐	☐	☐	☐
5. ARVR allows me to apply learnt theory into practice	☐	☐	☐	☐	☐
6. I can apply learnt theory into practice in traditional learning	☐	☐	☐	☐	☐
7. ARVR smoothly acts as I planned the activities	☐	☐	☐	☐	☐
8. I can plan my activities in real life as in ARVR smoothly	☐	☐	☐	☐	☐
9. ARVR allows me to retry and test out my assumption easily	☐	☐	☐	☐	☐
10. I can retry and test out assumption in real life as in ARVR easily	☐	☐	☐	☐	☐
11. The conceptualization of the landscape theory can be applied to the ARVR	☐	☐	☐	☐	☐
12. I can apply the conceptualization of the landscape theory to real life easily with traditional learning	☐	☐	☐	☐	☐
13. After the operation of the VR, I have deeper understanding of the landscape theory learnt on paper	☐	☐	☐	☐	☐
14. I can have deep understanding of the landscape theory by simply reading from paper	☐	☐	☐	☐	☐
15. I have gained experience from operation of ARVR and feel more confident to solve real-life problems	☐	☐	☐	☐	☐
16. I can gain same experience from traditional learning and feel confident to solve real-life problems	☐	☐	☐	☐	☐
17. Aside from the operation of the AR, the activity allows me to think critically	☐	☐	☐	☐	☐
18. I am able to have same level of critical thinking with traditional learning	☐	☐	☐	☐	☐
19. ARVR encourages more frequent reflective thinking, as I can redo, revise, and review my progress with no constraints of time/space/venue etc	☐	☐	☐	☐	☐

Please answer these questions

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
20. I am able to have reflective thinking, redo, revise and review my progress without any constraint easily in traditional learning	☐	☐	☐	☐	☐
21. ARVR allows my peers to observe my action and make peer review judgements and I can learn from each other	☐	☐	☐	☐	☐
22. My peers can observe my action and make peer review easily in traditional learning	☐	☐	☐	☐	☐
23. ARVR offers a cost-effective method to mimic real life tree felling, which is an efficient method used for future learning during pandemic	☐	☐	☐	☐	☐
24. Traditional field trips are costly and hard to organize during pandemic	☐	☐	☐	☐	☐
25. ARVR provides a sustainable method of learning and teaching during pandemic	☐	☐	☐	☐	☐
26. ARVR is cost-effective means to develop teaching and learning materials	☐	☐	☐	☐	☐
27. ARVR has high demand on IT support and equipment requirements	☐	☐	☐	☐	☐

Appendix II: Qualitative interview questions

1. Based on Kolb's Experiential Learning Theory, which emphasizes the importance of learning through experience and reflection, how do you feel your design and tech education has allowed you to engage in hands-on learning and reflective thinking? Can you provide specific examples of projects or assignments that contributed to your experiential learning process?
2. Kolb's Learning Cycle consists of four stages: Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation. In your design and tech education, which of these stages do you feel is most emphasized and well-developed? Are there any stages that you believe could be improved or incorporated more effectively in your educational experience? If so, how?

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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