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Towards an Edu-Metaverse of Knowledge: Immersive Exploration of University Courses

Zackary P. T. Sin, Ye Jia, Astin C. H. Wu, Isaac Dan Zhao, Richard Chen Li, Peter H. F. Ng, Xiao Huang, George Baciu, Jiannong Cao, and Qing Li

***Abstract*—Metaverse, an alternative universe for play, work and interaction, has become a captivating topic for academia and industry in recent times. This opens the question on what a metaverse for education, or edu-metaverse, should look like. It is believed that this metaverse for learning should be grounded by a pedagogical theory. Particularly, we propose a constructivist metaverse learning theory with eight actionable principles to guide the edu-metaverse and its applications. With this metaverse learning theory, we further propose the framework for an edu-metaverse; it is essentially walkable yellow pages that connect knowledge. The core idea is to combine the structure of knowledge graphs and the immersion of virtual reality in order to facilitate association, exploration and engagement in learning. Our current prototype for this edu-metaverse vision, K-Cube VR, is also presented. We have tested K-Cube VR for the introduction of course topics to our students and the results indicate that our edu-metaverse framework benefits students by providing a focused environment and structured learning on the topics of a course, akin to a mind map. Overall, in this paper, we present an edu-metaverse design that is rooted in a constructivist pedagogy that already shows promising results from a pilot user study via our metaverse prototype.**

***Index Terms*—education metaverse, metaverse learning, virtual reality, knowledge graph, immersive learning, constructivism, e-learning tools**

I. Introduction

WHAT is the future of learning in the metaverse? For metaverse, there are dozens of definitions for this hot topic, ranging from social to technical aspects [1], [2]. Some definitions focus on seamlessly merging the virtual and physical world with extended reality (XR). We found that, however, it seems most of these nomenclative discussions focus on the social and entertainment impact of metaverse, but lack in providing a clear path for an education metaverse. As the academic interest in the metaverse has grown recently, it is important to address how learning in this alternate universe should evolve, or perhaps, even begin [3].

We look at the metaverse not necessarily as a digital twin or replica of the real world [1], [2], but as a virtual world that can enhance, substitute or enable activities that may be difficult to achieve in the real world. Combining the discussions from previous scholars [4]–[6], our definition of the metaverse is that it is a *platform that provides access to interconnected content via physical metaphors that can complement activities that may otherwise be difficult or less efficient to achieve in the real world*. It encapsulates several properties of a metaverse: (1) it is potentially a ubiquitous platform for visiting content like a web browser; (2) it is appealing because its easy to use interactions based on physical metaphors; and, (3) its purpose is to complement the real world for activities ranging from entertainment to productivity. Particularly in our context, there is a necessity to understand the unique advantages the metaverse can bring to education. Better yet, these advantages need to be linked to current pedagogical theories such that the design of content in the education metaverse can be guided by theoretical principles.

We propose an edu-metaverse theory based on constructivism, one of the most influential pedagogical theories that are utilized by educators [7]. Its principle idea is that knowledge is an internal construct of the mind. As such, each individual will have his/her own understanding or interpretation of the world depending on how s/he internally constructs the world [8], [9]. Educators over the decades have proposed constructivist principles that can guide teaching and learning process. Although there are many views on the exact details, the general idea is to help the learner's internal knowledge construction process by engagement and association. To connect this central theoretical pillar to metaverse learning, we look at recent educational trends that are related to metaverse, immersive learning (IL) and visual literacy (VL). The former is heavily coupled with XR, while the latter is a useful tool for expressing abstract concepts. Together, their literature can give insights into content delivery and learner experience in an edu-metaverse. Further, collaborative learning (CL) is another topic of interest as its literature provides guidance on how students can learn together in a metaverse. We will later show how these theoretical discussions and trends can form our edu-metaverse theory. Eight actionable principles are produced in this theoretical contextualization which can be used as a guideline for future metaverse applications on learning.

Based on the proposed theory and its principles, we further propose a framework for an edu-metaverse. In contrast to many metaverses that aim to, more or less, replicate the real world digitally, our edu-metaverse aims to connect all the educational concepts and content in an interconnected structure in the form of a knowledge graph (KG). This academic *yellow pages* of

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Zackary P. T. Sin, Jia Ye, Astin C. H. Wu, Richard Chen Li, Peter H. F. Ng, Xiao Huang, George Baciu, Jiannong Cao, and Qing Li are with The Hong Kong Polytechnic University, Hong Kong, Hong Kong SAR (e-mail: csptsin@comp.polyu.edu.hk, aimmeng-ye.jia@polyu.edu.hk, chunwu@polyu.edu.hk, richard-chen.li@polyu.edu.hk, peter.nhf@polyu.edu.hk, xiaohuang@comp.polyu.edu.hk, csge-orge@polyu.edu.hk, jiannong.cao@polyu.edu.hk, csqli@comp.polyu.edu.hk). Isaac Dan Zhao is with Stanford University, Stanford, USA (e-mail: ikezhao@stanford.edu).

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connected educational concepts is visualized as an explorable virtual world in virtual reality (VR) for its immersive benefits. This edu-metaverse will also have (1) a knowledge hub for displaying multimedia content; (2) avatars that facilitate multi-user discussion of educational content; (3) an open platform for connecting immersive learning content; (4) learning content creation; and, (5) social features for personalized learning. We will show how these design elements are linked with the eight principles of our metaverse learning theory.

To move towards our vision for the edu-metaverse, and to capture preliminary user behaviour and feedback that provide early empirical support for this novel metaverse idea, we also present our prototype that partially implements the theory and framework proposed, Knowledge-Cube in VR (K-Cube VR). It provides a 3D immersive environment for users to explore knowledge. A pilot user study on course self-introduction is conducted with K-Cube VR. Students are asked to use K-Cube VR to understand an overview of a course on their own. The knowledge of a course is organized into keywords and their relationships, which are visualized in the form of nodes and edges, respectively. Multimedia content is also presented within the virtual environment to help the students understand the educational concepts. Aside from K-Cube VR, students were asked to grasp the overview of a course by interacting with a screen-based 3D KG and viewing documents on screens. Focus group discussions were also conducted to extract qualitative insights. The result shows that a metaverse of knowledge like K-Cube VR can help students to develop a more comprehensive understanding of a course. We postulate that the combination of KG's structure and VR's immersion is perhaps the key to its success. Aside from showing some of the unique properties of learning in a metaverse, the pilot study also partially validates the proposed metaverse learning theory.

In summary, our paper proposes how an education metaverse can manifest in the near future. A theoretical discussion is first presented in Section III which produces a metaverse learning theory with eight actionable principles that can act as a guideline for future applications. Then, from this theory, we propose an edu-metaverse framework in Section IV that uses VR to immersively explore a KG of knowledge. An early prototype of this metaverse, K-Cube VR, is presented in Section V. The pilot user study with K-Cube VR provides promising empirical support for our vision for the edu-metaverse. This paper extends our theoretical work [10] for a proposed framework design and a prototype coupled with a pilot user study. Overall, the contributions of this expanded paper are as follows:

- Propose a metaverse learning theory based on constructivism with eight actionable principles (from [10]).
- Propose a design for an education metaverse that enables immersive exploration and learning of knowledge within a structured world in the form of a knowledge graph
- Present an evaluated pilot metaverse prototype, K-Cube VR, which partially validates the proposed edu-metaverse theory and framework.

II. Related Work

As our edu-metaverse discussion is related to XR and KG, in this section, we present some of the educational and visualization works investigating them. The literature shows that there is a lack of discussion on utilizing XR and KG for an edu-metaverse.

IL works are essentially investigations on utilizing XR for education. It has already been shown to be effective in various educational contexts. For instance, it has enhanced and extended classroom education [11], assisted in science education [12]–[14], raised social issues awareness in an engaging way [15], and simulated natural disaster protocols for public safety [16]. There is also an investigation on how to improve the effectiveness of IL via pedagogical agents [17]. However, the literature seems to indicate that research on learning outcomes, intervention characteristics, and assessment measures associated with XR in education has been sparse [18]–[20].

KG is a graph for representing relationships between concepts. It has wide applicational potential within numerous domains such as medical, cyber security, financial and education [21]. In the education domain, there has been an attempt to visualize educational events and news [22]. There are also works demonstrating how to construct an educational KG [23], [24]. KG is not limited to visualization and has been shown to be useful for course management [25]. Analyzing the relationships in KG is also interesting to educators. KnowEdu is a system that can not only generate KGs automatically by applying recurrent neural network models, but also provide relationship analysis on students' assessment data [26]. To cater to the large scale of a knowledge-rich graph, concept graph learning was proposed with a framework for within-level and cross-level inference to organize the KG at course level and concept level [27].

There are works that use VR to explore graph-like structures. VRNetzer [28] visualizes graph networks in VR for analysis; it has been demonstrated as a tool for exploring molecular networks in genome-scale, thereby identifying genes for disease understanding. How a KG can be interacted with in VR has also been investigated [29] with a user study, which shows that VR is a preferable method of exploring KG compared to mouse-keyboard pair and joypad control. Besides that, the design of layout, rendering, and interaction for VR graph visualization via a spherical layout has been discussed, and it was found that a spherical layout is better than a 2D layout [30]. The navigation techniques for a 3D graph visualization such as teleportation and flying have also been explored [31]. On the other hand, there is work that explores visualizing 3D graphs via a CAVE system (e.g. cubical, spherical and cylindrical CAVE) [32]. Our work presented here differs in that it is designed for students to explore an academic domain, helping in scenarios like course introduction.

III. A Theory for Edu-Metaverse

What should be the guiding philosophy of an education metaverse? Since its principle function is to assist learning, the design for such a metaverse and its applications should be driven by an underlying pedagogy. In this section, we discuss how constructivism, IL, VL and CL can together form into our edu-metaverse theory. A key outcome is eight actionable principles that are concrete guidelines that can be used for the design and development of a metaverse for learning.

A. Constructivism

A well-known term for educators, *constructivism* has footprints across a wide spectrum of disciplines such as education, psychology and sociology. However, all variants of constructivism are rooted in their original place as an epistemology – a theory on the nature of knowledge that investigates how and why knowledge is created. Limited by the scope of this paper, we focus on providing an overview of constructivism to enable our theoretical discussion.

In contrast to more classical learning theories that postulate that the world is full of static knowledge and that the process of learning is simply a matter of absorption [33], constructivism believes that knowledge is an internal mental construction. Scholars commonly attribute the origins of this brand of constructivism to developmental psychologist Jean Piaget [9]. Piaget developed his "genetic epistemology" (an early form of constructivism) in the early twentieth century; he opined that "all structures are constructed" [34] and that with respect to the process of acquiring knowledge, "the fundamental feature is the course of this construction: Nothing is given at the start except some limiting points on which all the rest is based" [35]. Scholars have ascertained that the main tenets of his constructivist theory are that all knowledge is synthesised by individuals, and that this process is determined by individuals' past experiences as well as their present interactions with their environment [8], [9].

As time passed, the theory has been extended through myriad branching paths over the past century [36]. A so-called *mild* constructivism, however, has core ideas that are more or less agreed upon by constructionists across the board [9]. It was in the later part of the twentieth century when constructivism was adopted by the educational academia [9]. This transfusion from epistemology to pedagogy, however, may have led to further heterogeneous views as a theory on learning cannot be directly translated into a theory on teaching. Although there may be numerous proposals for constructivist principles on teaching, the general idea still stands: learning is a process that occurs when the learner grapples with new concepts, not when the instructor presents them.

Here, we adopt the pedagogical principles mostly compiled from the comprehensive literature reviews on constructivist teaching by Honebein [37] and Murphy [38]. According to them, constructivist teaching embodies these principles and goals (from [37] and [38]): (P1) *Provide experience with the construction of knowledge*, the learners need to be aware of the constructedness of the known knowledge of the world; (P2) *Embed relevance in learning*, the learners need to be able to relate to what they already knew; (P3) *Provide experience in and appreciation for multiple solutions*, the learners need to be exposed to multiple perspectives to have a robust understanding; (P4) *Embed learning in a realistic and authentic context*, associating knowledge to reality helps engage the learners and facilitate relevance; (P5) *Encourage ownership during learning*, engaging the learners to seek knowledge on their own can help expand the learning domain; (P6) *Encourage usage of multiple representations*, knowledge should be exposed to the learners in different views to help them conjure a complete picture of a concept; (P7) *Emphasize exploration to encourage students to seek knowledge independently*, learners should be provided with opportunities to explore new knowledge; and, (P8) *Embed social learning*, learning should ideally be done socially such that learners can correct one another's understanding.

B. Immersive Learning

With the advent of XR, educators have been increasingly interested in utilizing it for education; this trend propels what is referred to as *immersive learning* (IL). A key appeal of XR is its ability to generate a sense of presence in the user, or a "sense of being in an environment" as Gibson [39] calls it. XR can induce this feeling by immersing users in the virtual environment via technologies such as VR head-mounted devices (HMD) and a high degree of freedom tracking controllers [40]. The crux of IL, therefore, is to generate a sense of presence such that the learner can act and behave as if the virtual learning environment is real, thereby enabling teaching material or experiments otherwise difficult to reproduce in the real world. Another important point is that the immersion of IL can help learners to focus on actually learning the educational content rather than grasping the interface. Some scholars also claim that since XR allows for immersion, interaction, and user involvement with the environment and narrative, it offers very high potential in education by making learning more motivating and engaging [41]. There is a rapidly growing body of works applying IL on a broad range of topics such as scientific education [12]–[14], simulation [16] and augmented classroom [11].

Scholars have highlighted some of the unique advantages of IL; particularly, Dede [42] proposed that IL benefits the learner via three properties, multiple perspectives, situated learning and transferable. A provided example of multiple perspectives is that the viewing of content can be divided into egocentric perspective that enables participants' actional immersion; and exocentric perspective that fosters participants to have more abstract and symbolic insights. Situated learning focuses on the presence component and is realized mainly by immersive interfaces. It includes authentic contexts and activities; assessment coupled with guidance from expert modeling and mentoring; and, legitimate peripheral participation. Transferable is defined as the application of knowledge learned in one situation to another situation [43]. On the other hand, Bailenson [44] proposed heuristics with four criteria (i.e., dangerous, impossible, counterproductive, and expensive) to form a basis for why and when IL ought to be used.

Due to the interactive nature of IL, there are works that started the discussion of linking IL with constructivism [45], [46]. We further this scholarly effort by integrating the properties of IL into constructivism more concretely, demonstrating

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how pedagogical principles can be adapted for metaverse learning principles. In particular, we believe IL's ability to provide social elements, simulated situations for practice [47] and engagement are some of the catalysts that are beneficial for constructivist learning.

C. Visual Literacy

Originally, *visual literacy* (VL) referred to the competence a person has in interpreting visual information [48]. It has since grown to have more formal definitions, for example, Avgerinou [49] concludes that there are four main aspects to VL, namely "visual perception", "visual language", "visual thinking", and "visual communication". Felten, on the other hand, [50] believes that VL can be separated into just the two sub-domains of "visual cognition and perception" and "visual design".

Particularly interesting to us is to utilize VL to help learners interpret, communicate, and construct meaning via visual language [51]. Like verbal language, this "visual language" has vocabulary, grammar, and syntax [48]. The basic components of its vocabulary can include but are not limited to points, lines, shapes, lights, colors, forms, and space [52]. This visual grammar should be organized and designed around the targeted visual content.

As the design of the visual language is a challenge, Roth [53] borrowed the design principles and concepts from fine art and applied them to digital media. She highlighted visual hierarchy, similarity, and proximity as some of the properties that VL can express. Visual hierarchy can be used to guide or shape the viewing experience by manipulating the viewing order and focus of attention such that by highlighting visual elements, the viewer can deduce a hierarchy of importance; similarity is used to indicate similar meanings, functionalities or types of information; and, proximity is a grouping principle that uses the perceptually proximity of elements to indicate closeness. We will later show how VL can benefit our edu-metaverse theory.

D. Collaborative Learning

In contrast to IL and VL which seems to be much less associated with constructivism, collaborative learning (CL) is an educational trend that has a mature connection with constructivism. The key of CL is to achieve a mental synergy during learning via mutual exploration and feedback among a group of students [54]. By cultivating an environment of inquiry, it is believed this form of social learning will help with the learners' knowledge construction. More important for metaverse's context, computer-supported CL (CSCL) is a specialized group of works on investigating how computers can be used to assist in CL. The key to CSCL is to facilitate social presence (student-student interaction), cognitive presence (student-content interaction) and teacher presence (teacher-student interaction) in a computer-mediated world [55]. These are important to investigate as users need to interact naturally with one another and with the content for an ideal group learning session, which supports inquiry. Among these, some scholars have argued that cognitive presence is the most critical component for CSCL as the content drives the other two types of interaction [56]. Henceforth, it is suggested that it is not the case that an interaction that replicates face-to-face interaction is the most ideal; instead, it should have collaborative functionalities that are not possible or difficult to replicate in the real environment [57]. For a CSCL environment, its interface can focus on facilitating content discussion via augmentation [58] or resource sharing [59].

E. The Metaverse Learning Principles

There is a lack of discussion on the pedagogy of an edu-metaverse. Over the years, constructivist educators have derived pedagogical principles to follow; and there is a large number of works attempting to implement a constructivist regime for students. However, it seems many of these regimes tend to stray from established principles of constructivism, and are limited in being mainly "learner-centric" [9], which may lack concrete and actionable guidelines. On the other hand, although IL and VL are gaining traction within academia, current works on them do not seem to anchor themselves into a greater pedagogical philosophy. Rather, they mainly investigate empirically how their immediate methodology can assist students.

We propose incorporating IL and VL into constructivism, which forms our edu-metaverse theory. Constructivism can provide a theoretical backbone that justifies and guides the features of an edu-metaverse while IL and VL can provide insights on content delivery and learner experience within a metaverse. We further incorporate CL to provide insights on how to facilitate social learning in an edu-metaverse. The result of the theoretical contextualization is the following eight metaverse learning principles, which are reformulations of the principles from Section III-A for the metaverse (Fig. 1):

(M1) *Present Knowledge as Visualised Construct:* A key idea of constructivism as an epistemology is that knowledge is an internal mental construct that requires organization within the mind. From a pedagogical perspective, it is important to let students know the nature of knowledge such that they can be more active and aware of its internal construction (P1).

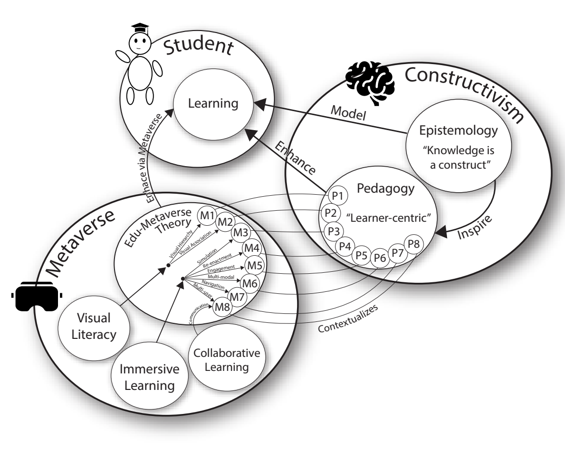

Fig. 1. The proposed education metaverse theory contextualizes constructivism for learning in metaverse by incorporating IL, VL and CL.

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Therefore, to demonstrate the knowledge construction process, VL can be used to assist learners by showing how knowledge can manifest and organize. Specifically, it is expected that VL's visual vocabulary can help students think visually, and thus structurally [60], which may benefit their knowledge construction. Roth's visual hierarchy and proximity [53] may particularly help with organizing knowledge as it can visualize different levels of abstraction.

(M2) *Associate the Knowledge:* Another idea of constructivism is that a new concept is understood based on previous knowledge of the learner (P2). Henceforth, VL's visual vocabulary (via similarity and proximity [53]) can show the associations between concepts to help students understand how knowledge interweaves, and from there, build new understanding.

(M3) *Provide Immersive Simulation:* Constructivism believes that one of the main purposes of knowledge is to model reality. It is important to allow the students to look at the same problem from different angles or with multiple solutions so that they can have a robust internal model (P3). An IL with situated learning can provide an immersive simulation environment where the student can complete a task via different methods and thus, become more robust in their comprehension.

(M4) *Re-enact Daily Life Problem:* According to constructivism, as learners use their own experiences in life as building blocks for new knowledge, it can be an effective strategy to link a subject of learning to a problem that they can encounter in real-life. Not only will this help the learners associate better with their experience, but it can also be more engaging to them as the problem is now practical to their daily lives. With IL's situated learning, we can re-enact daily life problems more convincingly in an immersive simulation where the process of solving a problem can be associated with real life (P4). In cases where VR may have difficulty recreating such a realistic environment, augmented reality (AR) may be an ideal alternative to inject virtual elements in real-life scenarios.

(M5) *Engage the Student in XR:* Constructivism is learner-centric; it means that students need to take ownership of their own learning (P5). IL has been shown to be able to engage students and therefore is a useful medium for students to naturally take the initiative to learn [61].

(M6) *Present Content via Multiple Modalities:* Constructivists advocate for the inclusion of multiple modes of representation to help learner robustly build a mental construction of knowledge (P6); this will benefit from a spatially adaptive content delivery modality like XR which can utilize the entire 360° view for presenting a diverse content conveniently [62].

(M7) *Facilitate Exploration of Knowledge:* Constructivism asserts that the user's exploratory interactions are important as a mechanism through which new knowledge is synthesised (P7). Ergo, the design of an edu-metaverse should provide the user the freedom to explore while giving guidance and structure during such an exploration. Aside from movement by teleportation, which is common for VR, egocentric and exocentric exploration of the knowledge is expected to give the learner different perspectives and insights within the knowledge landscape.

(M8) *Embody Social Learning Avatars:* Another belief of constructivism is that learning in a group can be ideal because learners of different experiences and personalities can challenge and guide one another (P8). To provide a fertile ground for social learning to flourish, previous CSCL works advocate that the interaction design needs to bear cognitive presence in mind such that the learner can interact naturally and with purpose [55]. Not only does this require IL's immersion, the interaction, particularly, also needs to assist the learner in communicating the educational content [57]. Thus, we advocate that the avatars representing the learners need not to physically resemble them, but be equipped with visually augmenting ability in a metaverse to conveniently express and communicate educational content to facilitate discussions.

IV. A Framework for Edu-Metaverse

What would an edu-metaverse look like? What features and interactions would this world include? With a metaverse learning theory, we now move on to propose a framework for an education metaverse. Based on our definition of a metaverse (Sec. I), we believe an edu-metaverse need to achieve the following: (1) it is a ubiquitous platform for visiting interconnected educational concepts; (2) it is easy to interact based on physical metaphors; and, (3) it complements real-world learning by bringing in the conveniences of digitalized content. The core idea for our yellow-pages-like edu-metaverse is to combine the structure of KG and immersion of VR for exploring educational content. In this section, we will present the key design elements of the framework which reflects the principles discussed in Section III.

(F1) *Knowledge Graph as a Walkable World:* The first question we ask when designing our edu-metaverse is what its world would look like. Many metaverses attempt to replicate the real world digitally in the form of digital replicas or digital twins. Here, we propose a radically different view on the nature of an edu-metaverse. It is not a world that attempts to reflect the real world but knowledge itself. The navigable world of the proposed edu-metaverse is a KG that connects educational concepts and content as shown in Fig. 2*a*. A KG consists of nodes and edges. Each node represents an educational keyword and each edge represents a relationship between two keywords. Effectively, the edu-metaverse is akin to a browsing environment or yellow pages of connected knowledge. Using a web browser as an analogy, a KG node is synonymous with an URL that groups and presents related content, while a KG edge is synonymous with a hyperlink that enables quick access to related knowledge.

Using KG as the core of an edu-metaverse serves several purposes within our proposed theory. Foremost, it is crucial to show the learner the knowledge construction process. This implies that we need to show the learner the nature of knowledge, which, according to constructivism is a mental construct that is organized. It is believed that KG is a natural medium to visualize or communicate this construct, and thus using KG adheres to the proposed metaverse learning principle M1. Further, learners need to utilize previous knowledge in order to understand new knowledge. This will require the association of

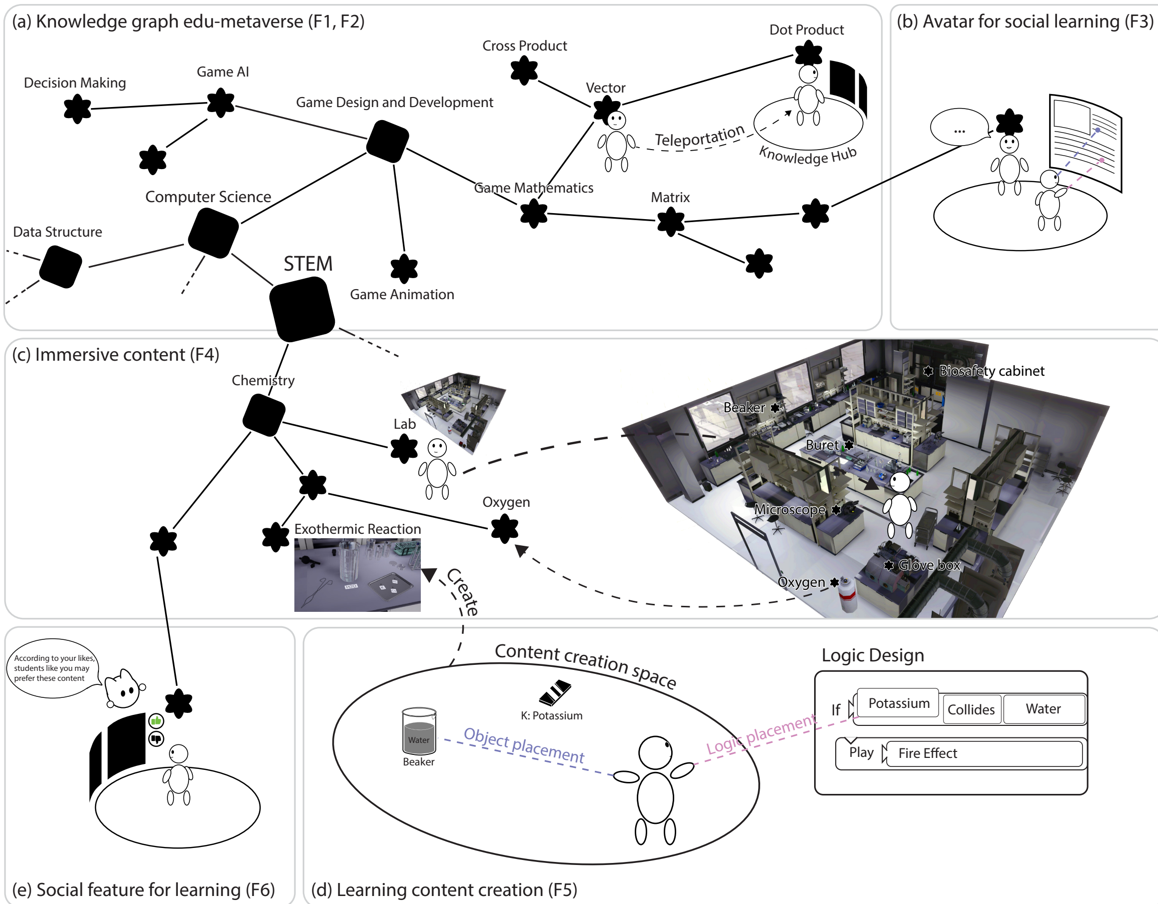

Fig. 2. The proposed education metaverse framework. *(a)* We propose an edu-metaverse that manifests as a KG where a node represents an educational keyword. A user can navigate by jumping from one node to another. Each node is also a knowledge hub for viewing multimedia content. *(b)* The avatar for the edu-metaverse should facilitate communication regarding the educational content. The pointing and viewing of a user can be highlighted via visual cues. *(c)* The KG of the edu-metaverse enables organization of and easy access to immersive content. With KG as a backbone, virtual objects within immersive content can be cross-referenced back to the KG itself. *(d)* Learning content can be created in the edu-metaverse to expand the library of immersive content. *(e)* Social features can be introduced to the edu-metaverse to support a feedback mechanism, which can further enable content recommendation.

knowledge as indicated by M2, and can naturally be achieved via a KG. Another interesting property we expect with the edu-metaverse lies in how learners will navigate in it. In order to traverse the KG, VR navigation that focuses on walking from node to node will be implemented. This will enable the learner to visit educational concepts that are related to one another conveniently by jumping between nodes. In contrast to typical educational content mediums (e.g. books, Wikipedia) that present concepts one by one sequentially, with the KG, our edu-metaverse presents related concepts simultaneously. We expect this to increase the exposure of learners to new concepts, which will, in turn, encourage free exploration of knowledge by the learners, echoing M7. Ultimately, it is hoped that the edu-metaverse's KG can encompass all the disciplines (e.g. from engineering to humanities), courses and their concepts; thus, enabling students to learn whatever subjects they so desire by simply exploring this metaverse of knowledge.

(F2) *Each Concept as a Knowledge Hub:* Of course, there is a need for the learner to understand an educational keyword within the edu-metaverse. Each node in the learning metaverse not only represents a keyword but also acts as the knowledge hub for the keyword. Within the hub, the learner will be able to access various multimedia content for learning the educational concept. The content can come in the form of lecture slides, Wikipedia, videos and more. It is important to provide different ways or perspectives to understand the same concept, as indicated by M6.

(F3) *Avatars Enhanced for Communicating Educational Content:* Embedding social elements is important as interaction between people can help develop knowledge and understanding as indicated by the principle M8. This will require an "ego" of the student, or avatar, to exist in the edu-metaverse. The key goal of this avatar is to facilitate communication between users; particularly, it should facilitate discussion with respect to the educational content (Fig. 2*b*).

Human communication relies on the exchange of several audiovisual signals. An important communication method is natural speech, but it is also quite important to let others know who is talking. Thus, our avatar will have simple speech animation for users to identify who is talking. Pointing at an object of interest is also a common way for us to communicate. Our avatar can mimic pointing via mapping its hands to the user's controllers or actual hands. This "hand" can help a student to point at the content in the edu-metaverse and discuss it with others. Further, some recent VR HMDs support eye tracking. Similar to reflecting where the hand is pointing at, our avatar's eyes can also reflect where the user is looking at to further help others know what the user is focusing on. Visual cues in the form of UI within the application can be used to highlight where the user is pointing at or where the user is looking at. This is expected to be particularly useful when the users are discussing educational content.

These features for the avatar are expected to help students to go into the edu-metaverse and explore educational knowledge together. On the other hand, we also expect it to be beneficial to teacher-student situations such as academic advising. The advisor can utilize the edu-metaverse to conveniently present educational content to the advisees to discuss what may interest or benefit them most. In the meanwhile, as the edu-metaverse presents data as if it is a "garden of data", the advisees can also look around to see if there are educational topics that interest them. As the avatar facilitates communications between users, the advisor can utilize different cues, such as where the advisees are looking at to infer what may capture their interest and initiate further discussions.

(F4) *An Open Platform for Connecting Immersive Content:* IL content provides a unique learning experience enabled by XR; they produce learning content that reflects reality (M4) or provides an experimental area for testing different solutions or ideas (M3). Although there is a growing number of XR applications for learning scientific experiments, playing interactive simulations or going virtual field trips which can be found in e-stores, we argue that the current heterogeneous landscape for XR learning apps where one application learns one thing has several disadvantages. For one, each XR application may have its own control interface. This means that before the user actually learns the educational material, they will first need to learn the interface each time, requiring students to devote extra time. Second, each application needs to have its own implementation for avatars and user interfaces, which may incur repetitive development costs. Third, an application, once published, takes time for it to be discovered and framed into an educational context. An open edu-metaverse can address these problems by providing a standardized environment for accessing this immersive content (Fig. 2*c*). If the users want to learn via immersive content, they simply need to go to the educational keyword in question and all the immersive content available will be there.

Further, the proposed KG backbone can also help atomize knowledge for easy cross-referencing across the metaverse, which benefits M2. The referencing will particularly benefit IL content. When the user has entered IL content, they can enter a "knowledge mode" to see how each object in the VR environment maps back to edu-metaverse's KG. This knowledge referencing is another unique advantage that can be provided by a ubiquitous metaverse.

(F5) *Learning Content Creation:* Content creation seems to be another feature that is associated to metaverse. For edu-metaverse, we believe that such content creation should focus on learning content, specifically, interactive simulations where students can test ideas and solve problems. Generally, two sets of tools should be provided for learning content creation, object placement and logic design (Fig. 2*d*). The former involves providing tools for the user to place, move, rotate and scale virtual objects and elements, which will enable them to first create the environment. Logic design tools akin to the ones in "Horizon Worlds" and "Little Big Planet" will allow the user to specify the logic between virtual objects to enable simulation. It is further suggested that this content editor should be provided in two ways, out-VR for educators and in-VR for students. By linking the created learning content to the KG, not only will it expand the IL content library of the edu-metaverse, it will also involve the student in the knowledge construction process (M1).

(F6) *Social Feature for Educational Content:* The social element of the edu-metaverse can be further expanded via typical social network features such as (dis)like, comment and share function (Fig. 2*e*). These social features are used upon the educational content linked with a knowledge keyword. If a student feels that a particular content helps them learn better, they can consider to "like" it. How many "likes" a content received can help a student consider which content to spend more time on for learning the keyword. In addition, as a student's "likes" can be utilized as a feedback mechanism for content recommendation, it should benefit M5.

V. K-Cube VR: A Prototype for Edu-Metaverse

The development and evolution of a metaverse take time. There is, however, a need to have a preliminary understanding of the properties of an edu-metaverse, particularly, its learning effect on students. Hence, to move towards our vision for a full-fledged edu-metaverse described in the previous section, K-Cube VR, the current prototype is presented here. As of this moment, the prototype has design elements F1 and F2 described in Section IV. We put forward course introduction as a use case for this prototype edu-metaverse. A pilot user study on utilizing K-Cube VR for course self-introduction is also presented.

A. Course Introduction: A Use Case

We believe that one of the potential use cases for an edu-metaverse is *course introduction*. Selecting a course is a recurring question every university student needs to answer every semester. For a fulfilling academic life, it is crucial for students to select courses that are suitable for their interests and/or career paths. Choosing their own courses, however, is not trivial. It has been shown that a third of university students have confusion in regard to course enrollment [63]. This may be related to the fact that students lack the background knowledge of their academic field to choose courses, but this overview of their field may only come to fruition after they study the courses. Thus, course selection often becomes a herd mentality phenomenon where students choose courses based on hearsay (e.g. which course is easier) [64]. Hence, it is important to provide support for students such that they can be informed about their academic domain.

To communicate with students on the overview of a course, generally, there are three main methods. (1) Students are

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provided with a general picture of a course in the first lecture. Through the lecturer, the students will grasp the key components and concepts. This introductory lecture is mainly designed to help students during the add/drop period if they feel strongly that they need to adjust their course selections after the first lecture; this means, however, that this mechanism may only serve a smaller population of students. (2) Academic advising is, of course, an important component of university life and can provide hands-on and personal guidance to students for their academic journeys. It seems, however, that there is not a significant trend in finding advisors for course selection every semester. The students, particularly those who are shyer, may feel that course selection is not important enough to seek help from their advisors every semester. (3) Academic departments almost always provide descriptive documents (e.g., syllabuses) of the offered courses. Although they may contain brief descriptions of the course contents, these documents seem to lean towards fulfilling an administrative role. Further, students may lack the fundamental knowledge to understand the high-level descriptions. Due to the lack of discussion on helping students to build an understanding, it is believed that an edu-metaverse can fill this gap by providing a method of *course self-introduction* for students, where they can discover and understand an overview of a course themselves.

B. VR Navigation and Interaction

K-Cube VR is the first step moving towards our edu-metaverse vision. Currently, it has design elements F1 and F2 discussed in Section IV. Through an HMD, the student will see a collection of nodes. A cube node represents the course while each star node represents the keyword of said course (Fig. 3*g*). The edge between the nodes is indicating a relation between nodes. Specifically, it indicates that A is a subtopic of B. Lastly, the circle represents the "space" of the course.

To navigate in the virtual space here, there are two main methods. The first method is teleportation (Fig. 3*a*), which is commonplace in VR applications [65]. The user simply needs to point at a location, press forward with the controller's thumbstick and this will teleport the user to the indicated location. The second method is node-teleportation (Fig. 3*b*). Instead of teleporting to an indicated location by pointing, node-teleportation sends the user in front of a node. The user first locks a node by pointing one and pressing the hand trigger. Then, while locking a node, s/he will be teleported to the node by pressing forward. When a user has teleported to a node, the graph layout will be reorganized such that the children nodes will also be in front of the user. This adaptive layout can help the user to view the local subgraph. To return to an "overview position" in VR such that the entire graph of the course can be seen, the user can node-teleport to the course node.

It is believed that understanding the keywords and major concepts of a course is an important step for a student to develop an overview. Multimedia content is provided for each keyword to help student understands what it is. Here, a keyword is linked with the corresponding lecture note slides and Wikipedia page (Fig. 3*c*). When the user is pointing at a keyword node, its lecture note slide will pop up. From here, the user can use the thumbstick to see the previous (left) page and the next (right) page of the lecture slides. To show the Wikipedia page, the user can press the button A. As the content will disappear when the user is not pointing at its related keyword, the user can also pin the nodes by pressing the button B. When a node is pinned, it can be grabbed to a desired location for easier viewing. So, to place a node at a specific location, the user can first pin the node with B and then grab the node by pressing both the index trigger and hand trigger. The user can then move the node, while grabbing, to the new location (Fig. 3*d*). Further, for the two panel-based content (lecture note slide and Wikipedia page), the user can tune the scale of the panel to help with his/her content viewing. This scaling can be done by grabbing the scaling anchor on the bottom right of the panel. The size of the panel will follow the anchor such that when it is grabbed away from the top-left corner, it will become larger (Fig. 3*e*). Note that the controller scheme only involves the right controller (Fig. 3*f*).

C. A Pilot User Study for Edu-metaverse

To evaluate K-Cube VR, we conducted our user study with a comparative analysis between modalities and data collection for knowledge performance and workload. Focus group discussions were also conducted to collect qualitative feedback from the students participants. A course for game development and design was used for the experiment.

1) Comparative Modalities: With K-Cube VR, there are simultaneously two added tools, VR and KG. In an attempt to see their effects on course self-introduction, three (interactive) modalities were utilized in the user study. Aside from K-Cube VR itself, students would self-introduce to a course via a 3D interactive KG played on a Desktop and via traditional course description documents to serve as a Control group. For Control (Fig. 4*a*), students would be presented with a default layout with documents on the left and Wikipedia on the right. Mainly, the most important document on the left is the subject description document. However, as there are lecture slides in the two KG modalities, those slides could also be viewed on the browser on the left side. For Desktop (Fig. 4*b*), the student would be presented with an interactive KG. S/he could use mouse control to move around the KG environment. The lecture note and Wikipedia could be accessed on the right and their content would be changed depending on which concept is selected on the left side.

2) Participants: A total of 45 student participants were recruited through advertisement and through a class. They were randomly divided to test different modalities with each having 15 users: Control with 3 females and 12 males, aged $\mu = 21.29$ ($\sigma = 2.23$) years old; Desktop with 5 females and 10 males, aged 21.27 (2.53) years old; and, K-Cube VR with 3 females and 12 males, aged 22.54 (1.81) years old. Among all users, 16 have reported to have experience with VR of which 5 are assigned to Control, 6 to Desktop, and 5 to K-Cube VR. We asked the students to use the content to grasp the overview of the course and to "take as long as they like".

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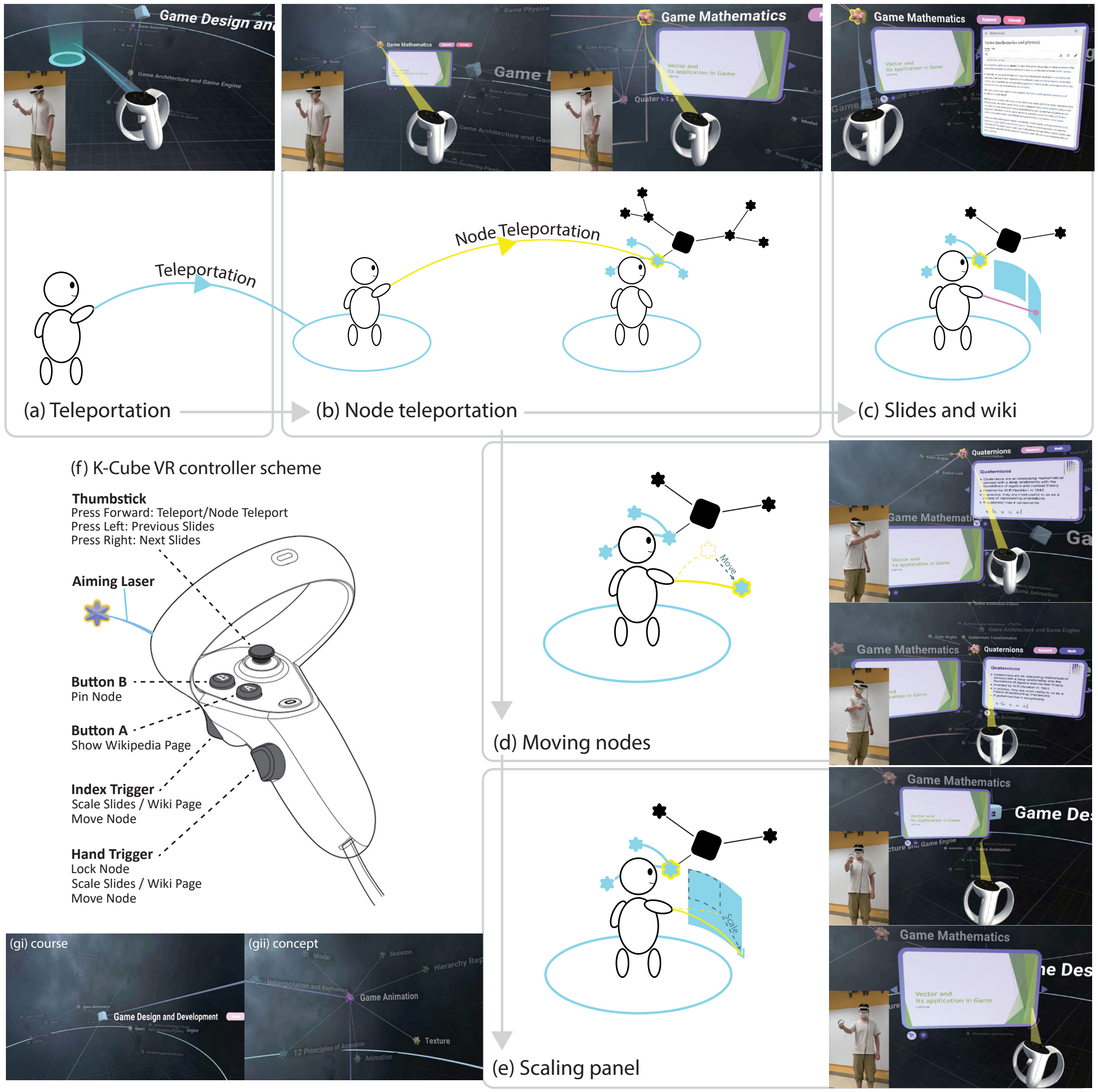

Fig. 3. The prototype for our education metaverse vision, K-Cube VR, can be navigated by *(a)* teleportation, *(b)* node teleportation. *(c)* Each keyword in K-Cube VR is linked with a lecture note slide and a Wikipedia page. *(d)* The node can be moved by grabbing. *(e)* The panel can be scaled up. *(f)* The controller scheme of K-Cube VR. In K-Cube VR, *(gi)* a cube represents a course while *(gii)* a star represents an educational keyword.

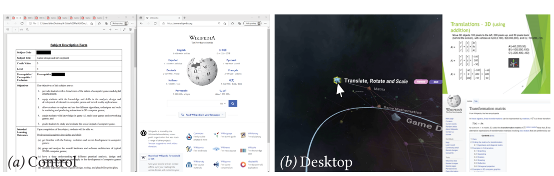

Fig. 4. The other two modalities used for comparison: *(a)* course documents (Control) and *(b)* a 3D interactive KG (Desktop). They are viewed on screens.

For the Control, Desktop and K-Cube VR, the interactive time were 25.78 (0.41), 22.13 (0.43) and 28.54 (0.54) minutes, respectively.

3) Equipment: The experiment was conducted in our laboratory. The equipment used to deliver the K-Cube VR was an Oculus Quest 2 HMD and a right-hand side controller. Typical desktop settings with a monitor, a keyboard and a mouse were used to deliver Control and Desktop.

4) Procedure: The procedure for the experiment was: *(1)* introduce the presentation modality to the student participant; *(2)* explain to the participant how to engage with the modality; *(3)* (K-Cube VR only) let the participant familiarizes him/herself the VR navigation. Then, reset the application when s/he is ready; *(4)* explain to the user that his/her goal is to have an overview of the course; *(5)* allow the participant to engage with the presentation; *(6)* give the questionnaire to the participant; and, *(7)* conduct the focus group discussion.

5) Measured Variables and Instruments: We are interested to know and capture the behaviour of a user when exploring a prototype edu-metaverse. To achieve this, information is extracted both quantitatively (variables) and qualitatively (themes). First, two research variables are measured in this study: the *knowledge* a user has on a topic; and, the *workload* required by the user to operate the modality. There was a knowledge test that asked questions regarding the know-how of the participant in the course (*knowledge* variable). Then,

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the *workload* (variable) of participants was collected by the commonly used NASA Task Load Index (NASA-TLX) [66], which provides 6 scales on different workloads. These were measured after the users were exposed to the content. To extract qualitative insight from the users, we have prepared several themes that are expected to manifest in the focus group: the ease of *comprehension* of the presented educational material (Sec. V-D3), the *immersion* the user experienced given the modality (Sec. V-D4 and V-D5), the usefulness of the different *perspectives* of a given content (Sec. V-D6) and the *challenges* for operating a modality (Sec. V-D7). These themes were later extracted via deductive coding technique. The questions designed for the focus group (Sec. V-C6) aim to provide opportunities for these themes to manifest.

6) Focus Group: Semi-structured focus groups were conducted to collect the participants' personal feelings about the content and presentation. The interview questions were asked sequentially as follows: (FQ1) "What is your first thought when you see this presentation?"; (FQ2) "Does this content provide you with an overview of the course?"; (FQ3) "Which part has helped you the most in understanding the course overview?"; (FQ4) "What else are you looking for in a course description?"; (FQ5) "Are you interested in this course?"; (FQ5a) "If YES for FQ5, Does the content motivate your interest in the course? In what way does it motivate you?"; (FQ5b) "If No for FQ5, Does the content give you an overview of the course such as you know it won't work for you?"; (FQ6) "In your personal opinion, what benefits users may get from this presentation?"; and, (FQ7) "In your personal opinion, what the disadvantage when users using this presentation?". The whole conversation was recorded and later transcribed. Verbatim quotes from participants were used as the basis for coding analysis. We assign the codes to the themes previously presented to discuss the properties of our edu-metaverse design. The size of the individual focus group sessions ranged from three to five.

D. Users in a Prototype Edu-Metaverse

In this section, we describe the key findings of the user study. They highlight the differences between different modalities. Particularly interesting to us are the benefits and properties of visualizing a course in the form of KG in VR, a key design element for our edu-metaverse vision.

1) Knowledge Gain: As indicated by our principle M5, a benefit of VR is that it engages the students more, and it is known that engagement can improve student performance [67]. Here, two knowledge questions were used to test the difference in performance. First, we asked the students to identify keywords that are related to the explored course. In the question, there are a total of 30 keywords with only 7 actually related to the course. In Fig. 5, the students' selections of course keywords are presented. As visualized in the figure, it is quite clear that students of the K-Cube VR group performed the best, followed by the Desktop's and last the Control group. From the figure, it also seems that the VR group students are less prone to selecting unrelated keywords. To aggregate the selection into an accuracy, we use intersection over union (IoU) to calculate a score. The IoU accuracy for keyword selection is $\text{IoU} = \frac{|\{\text{correct keywords}\}\cap\{\text{selected keywords}\}|}{|\{\text{correct keywords}\}\cup\{\text{selected keywords}\}|}$. The average (SD) IoU accuracy for Control, Desktop and K-Cube VR are 39.70% (11.14%), 55.19% (16.42%) and 59.81% (18.01%), respectively. K-Cube VR group's improvement over that of Control shows greater statistical significance ($p < 0.001$) compared to Desktop ($p < 0.01$).

Further, to see if there is more in-depth insight or understanding of the course, we asked the student the following question, "Please, in your own words, describe what this course entails with at least 50 words". It is not easy to directly compute a score for this kind of textual response. As such, we try to measure the perceived confidence of students instead which has been shown to correlate with knowledge [68]. The perceived confidence for Control, Desktop and K-Cube VR are 3.87 (0.92), 3.80 (1.01) and 4.07 (0.88), respectively. Overall, the performance of K-Cube VR seems to lean toward validating the engagement that comes with improved learning in an edu-metaverse.

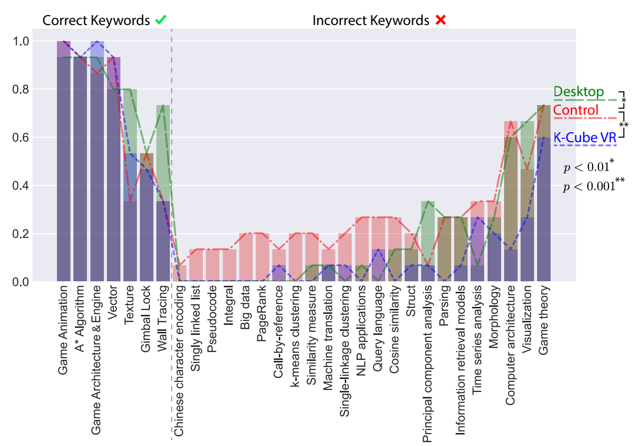

Fig. 5. Students' selections of the course keywords. Left (right) is the correct (unrelated) keywords. Red (green/blue) represents Control group (Desktop/K-Cube VR). A bar is showing the percentage of students selecting said keyword. The colored line highlights the selection of keywords for each group.

2) Competitive Task Workload: One of the major concerns for VR is that it is a new modality of interaction and that students may have difficulties adapting this method for learning. To evaluate the workload between the three modalities, the NASA Task Load Index (NASA-TLX) [66] was used. The result (lower is better) is shown in Fig. 6. The mean NASA-TLX score for Control, Desktop and K-Cube VR are 5.51 (0.85), 5.98 (1.59) and 5.43 (1.28). The result indicates that the workload difference between VR and non-VR methods is not significant; therefore, a VR approach to course self-introduction will not result in additional load to the students compared to a non-VR one.

3) The Importance of Structure: In our proposed edu-metaverse (K-Cube VR), knowledge becomes a visualized construct in the form of KG, and therefore, it is expected to be a natural medium for communicating knowledge. Specifically for our case, it is expected to be efficient in communicating the overview of a course to students. To see the effect of KG on the students, focus groups are conducted for all three modalities, Control, Desktop and K-Cube VR. We expect

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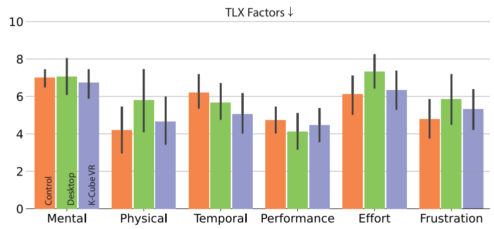

Fig. 6. The NASA-TLX factors' scores of different modalities, Control (red), Desktop (green) and K-Cube VR (blue).

that students between Control and the two KG modalities will have different feedback in regard to the knowledge structure.

For the Control group, when asked about what they are looking for in a course description (FQ3), a student replied in relation to the structure of knowledge. (Student01) *"I think it would be better to categorize them more specifically like this part is how to do that, and that part is how to do other things"*. When we clarified by asking, *"So you feel it could be structured more clearly?"*, s/he replied *"Yeah."*

The Desktop group, when asked about which part of the content has helped with their understanding of the course (FQ3), responded on the usefulness of structure. (Student02) ***"I think I would have a better understanding of the content because I can find that the concepts are linked together."***. Another said (Student03) *"I think the graph is the best for me to learn - because **I just need to know about their relationship** and this can show me about the relationship of different parts."* When asked with FQ6, the participant further complements that (Student02) *"I think it is clear to find out the important concept of the course."*.

The K-Cube VR group had similar sentiments to the Desktop group regarding graph and structure, particularly when asked about FQ3. (Student04) ***"The tree diagram (KG) is really convenient. So I can have a big picture of the subject.** I can know what's the subtopics and below the subtopics, what are the details"*. (Student05) *"I have the feeling that because **I can see that the nodes are connected with each other,** ... and I want to say **it helps my memory better** ... (And) actually it helps a lot, especially when I do the (knowledge test), I can have that view. If I can review or revise the materials again, I can exactly or I can fill the (knowledge test) very quickly and **have a very good picture of the structure of the content.**"* (Student06) *"I think the structure is like a tree... The strength is that **I can know which concept is the key** ... (and) **belong to which big (knowledge cluster)**"*. With FQ6, a student complements that (Student04) *"I will say **you can have a better understanding because when you just use VR technology the whole mind map is just shown** on your (HMD) and **you just know what is the structure of the course**"*. S/he also commented that without KG, (Student04) *"... when you read access to the blackboard, it just only shows the proper presentations, but there is no connection between topics that mentioned in the course, so hence there is no any mind map that will provide in the backboard platform."*

The replies from the student participants indicate that placing structures upon knowledge is useful for course self-introduction, which is predicted by the proposed metaverse learning principles M1 and M2 (from Section III) in that knowledge need to be presented as a visualized construct and that showing relationships of academic concepts are significant to learners. Further, the students' replies indicate that quite a few of them are informed about mind maps and have associated them with KG. Overall, the discussion on structure seems to support the usefulness of KG for learning.

4) Immersive Course Exploration: As mentioned, a key appeal of XR is that it can bring us a feeling of "being there", or presence [39]. One of our expectations is that, within a metaverse (prototype), students will forgo their physical surroundings and be immersed in the virtual exploration of the KG, becoming more focused.

A student remarked that (Student04) *"I feel that when I enter the VR, as I am immersed in the environment, **I kind of lose track of time and focus on the content of the VR.**"*, when asked FQ6. Further, (Student04) *"The audio also helps me feel immersed in the virtual environment."* This also provides some support to the importance of engagement of VR, which can benefit learning (M5).

5) Walking in Metaverse to Build an Internal Mind Map: As mentioned, an immersive environment can maximize the sense of presence, leading to changes in human behaviour [69]. Thus, K-Cube VR may have a better performance in helping participants to build an internal mind map. If so, what will be this building process? We asked the participants focus group question FQ2. (Student05) "***I can move the nodes around and organize them in my mind, which helped me to consolidate my memory.***" Then we asked about the benefit they got from the metaverse experience (FQ6). (Student07) " *I think I have a better memory of what I have just read. For example, **when I close my eyes, I can still have the visual image in my brain to remember** what I have encountered, which also acts as retrieval cues to help me to record what I have seen."* The feedback that comes from students can show that walking in a metaverse of knowledge indeed can help to build an internal mind map, and may indicate success in incorporating M7.

6) Spatial UI for Content Viewing: Parallel browsing is the behaviour of concurrently visiting multiple tags. Multiple windows and tabs browsing in 2D may have flaws that hinder user performance due to limited UI space. However, a VR browsing environment can improve user viewing efficiency because of its tangible interaction pattern and greater space for browsing content [62]. There is also evidence that spatial UI design can decrease the number of manual interface adaptations [70]. Thus, viewing the content in VR space should be more convenient for the user.

We asked participants focus group question FQ1. (Student05) "*I think it is **quite interesting and useful to see the PowerPoint slides with the Wikipedia website in the VR space** because it is a different experience compared with viewing them through a computer screen.*". This feedback may be related to M6, which advocates the importance of multiple modes of knowledge representation. We then asked participants their specific feelings. (Student04) "*In the real world, we only can view content through a flat paper or a flat screen, but **in the VR space, we have a 3D object, so it brought me a new viewing experience (angle)** that I had* *never seen before.*" Therefore, it seems that the spatial UI of VR can indeed provide a helpful viewing experience by expanding the presentation space which diversifies UI content for simultaneous viewing.

7) VR Fatigue: Although there are key advantages for K-Cube VR, when asked FQ7, some participants have indicated a key challenge of VR, the fatigue that it will cause to some. (Student08) "*The VR device makes my eyes very fatigued and the device quite heavy, which makes me can't wear it for a long time.*" This is a general issue with VR hardware that may or may not be related to social-cultural familiarity with it. It may be the case that as metaverse becomes more popular, this issue may be less of a concern. We may also count on hardware manufacturers to develop more comfortable HMDs in the future. Alternatively, lighter AR devices such as Magic Leap One may better entice users to adapt to XR technologies.

Overall, not only does the user feedback shows promising benefits for learning in a metaverse, it also partially validates the proposed metaverse learning theory.

VI. Conclusion and Future Work

Our vision for an education metaverse deviates from the common perception that it needs to resemble the real world; we envision an edu-metaverse that aims to assist students in exploring and learning new knowledge by walking on a KG. The core contribution of our paper is an edu-metaverse design that is rooted in pedagogical theory and backed by a prototype that already shows encouraging results. We believe our work solve a pressing issue for edu-metaverse on how it can manifest to connect a broad range of learning material and educational concept together on a ubiquitous platform for users to learn and explore knowledge. We anticipate that our academic yellow-pages concept can allow content creators from academia and industry to quickly deploy educational material on a platform.

In this paper, K-Cube VR is used for a pilot user study to discuss user behaviour in an edu-metaverse. Although user feedback and quantitative results show that K-Cube VR can assist in memorization, organization and better content viewing without accruing additional workload, the effect sizes of these benefits are not fully investigated. We can measure an isolated benefit for its conclusive effect size with a larger experiment population in future works. Also, since K-Cube VR is only a prototype, which is only the first step to realizing an edu-metaverse, the metaverse learning principles are not fully utilized yet. Hence, some of the benefits regarding social learning and learning in immersive content (e.g. simulation) when coupled with the edu-metaverse also require further investigation. Another limitation is that the current experiment only consists of a session done within an hour. It is also important to investigate the long-term effect of an edu-metaverse on students. We aim to address these limitations in the future as we extend K-Cube VR into a more complete metaverse of knowledge.

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Zackary P. T. Sin is a research assistant professor at The Hong Kong Polytechnic University (PolyU), where he received his Ph.D. and B.Sc. degrees. He is an experienced multimedia researcher and developer with publications in SIGGRAPH i3D, CHI Play and Pacific Graphics. His main research areas are metaverse, computer graphics and human-computer interaction. For education, his interest lies in enabling novel learning experiences in an edu-metaverse. This has been exemplified by his publications in EDUCON, ICWL and ICBL.

Ye Jia received his B.Eng from Chongqing University Of Arts and Science. He is currently a research assistant at the Department of Computing, The Hong Kong Polytechnic University. His research interests include human-computer interaction, extended reality.

Astin C. H. Wu received his BSc. in Computing and is currently working as a project assistant at PolyU. His expertise is in virtual reality and metaverse. His main research interest lies in human-computer interaction, especially in utilizing virtual reality and metaverse to increase efficacy in education.

Isaac Dan Zhao is currently pursuing a BSc. in Computer Science from Stanford University. His research interests include artificial intelligence and human-computer interaction.

Richard Chen Li is currently a research assistant professor of the Department of Computing, the Hong Kong Polytechnic University. He received the BSc in computer science and technology from Nanjing University, and the MSc (Distinction) in computer science and PhD from the City University of Hong Kong. His research interests include virtual reality, human-centred computing, serious games, and educational technology.

Peter H. F. Ng is currently an Assistant Professor in the Department of Computing (COMP) and Rehabilitation Sciences (RS) at PolyU, and he is in charge of the Game Lab and deputy programmer leader of FT Broad Discipline of Computing (EIS Steam) in COMP. His interests are AI, health application, APP, games and XR development. He received his BSc, MSc and PhD at PolyU in 2004, 2007 and 2013. He received one of the best ACG+ Capital teams from the Hong Kong Home Affairs Department in 2017, Merit Awards of Teaching by PolyU FENG in 2017 and 2021, Team awards of Teaching by PolyU FENG in 2021, Merit Awards of Service by PolyU FENG in 2019, Gold winner for the Community Outreach Award (eLFA2021) in 2021, Best ten teachers in the Greater Bay Area STEM Excellence Award 2022 (HKSAR).

Xiao Huang is an assistant professor in the Department of Computing at The Hong Kong Polytechnic University. He received Ph.D. in Computer Engineering from Texas A&M University in 2020, M.S. in Electrical Engineering from Illinois Institute of Technology in 2015, and B.S. in Engineering from Shanghai Jiao Tong University in 2012. He is a program committee member of AAAI 21-23, ICLR 22-23, NeurIPS 21-22, KDD 19-22, TheWebConf 22-23, ICML 21-22, IJCAI 20-22, CIKM 19-22, WSDM 21-23, SDM 22, ICKG 20-21.

George Baciu has been a Professor in the Department of Computing (COMP) at the Hong Kong Polytechnic University (PolyU). He holds degrees in Applied Mathematics and Computer Science, and a PhD in Systems Engineering from University of Waterloo. He has been member of the Waterloo Computer Graphics Lab and the Pattern Analysis and Machine Intelligence (PAMI) Lab. Dr. Baciu is the founding director of the GAME Lab at HKUST in 1993, and the Graphics and Multimedia Applications (GAMA) Lab in 2000 in COMP, PolyU. His research interests include Information Visualization, Cognitive Computing, Cloud Computing and Distributed Machine Learning, VR and Computer Graphics, with applications to cognitive digital agents, digital twins, motion synthesis, animation, collision detection, geometric modeling, and image analysis. He has published extensively in computer graphics, image processing, and VR journals and conferences and has served as chair of intl. conferences such as Game Technology Conference (GTEC), Pacific Graphics, VRST (and VRCIA), Eurographics, CGI, CAD/Graphics, and Computer Animation and Social Agents (CASA), IEEE Intl. Conf. on Cognitive Informatics and Cognitive Computing (ICCI*CC). He is a member of IEEE and ACM.

Jiannong Cao (Fellow, IEEE) received the M.Sc. and Ph.D. degrees in computer science from Washington State University. He is currently a Chair Professor with the Department of Computing, The Hong Kong Polytechnic University (PolyU). He is also the Dean of Graduate School, the Director of Research Institute of Artificial Intelligent of Things and the Internet and Mobile Computing Lab, and the Vice Director of the University's Research Facility in Big Data Analytics with PolyU. He has coauthored five books, co-edited nine books, and published over 500 papers in major intl. journals and conf. proceedings. His research interests include distributed systems and blockchain, wireless sensing and networking, big data and machine learning, and mobile cloud and edge computing. He is a member of Academia Europaea and an ACM Distinguished Member.

Qing Li (Fellow, IEEE) received the BEng degree in computer science from Hunan University (Changsha, China), and the MSc and PhD degrees in computer science, from the University of Southern California (Los Angeles, USA). He is currently a Chair Professor with the Department of Computing, The Hong Kong Polytechnic University. His research interests include multi-modal data management, conceptual data modeling, social media, Web services, and e-learning systems. He has authored or co-authored more than 500 publications in these areas. He is actively involved in the research community. He is a Fellow of IEEE, AAIA, IET(UK), and a Distinguished Member of CCF (China).