Towards a Metaverse of Knowledge
A Constructivist Proposition on Immersive Learning and Visual Literacy

Zackary P. T. Sin[1][0000−0002−8377−0216], Isaac Dan Zhao[2], Astin C. H. Wu[1], Richard Chen Li[1][0000−0002−3782−0737], Peter H. F. Ng[1][0000−0002−9671−896X], Xiao Huang[1][0000−0002−3867−900X], George Baciu[1][0000−0002−1766−6357], Jiannong Cao[1][0000−0002−2725−2529], and Qing Li[1][0000−0003−3370−471X]

[1] The Hong Kong Polytechnic University, Hong Kong, Hong Kong SAR
{ptsin, chunwu, richard-chen.li, peter.nhf, xiao.huang, csgeorge, jiannong.cao, qing-prof.li}@polyu.edu.hk
[2] Stanford University, Stanford, USA {ikezhao}@stanford.edu

Abstract. The academic success of students can be improved by an understanding of the academic domain they are navigating. As such, they may benefit from gaining valuable perspective into the shape of their chosen field via an enhanced visual aid. We discuss K-Cube VR, a work-in-progress academic domain browser, which provides visualization of such information through knowledge graphs in virtual reality. We then present the theoretical motivations of such a project, proposing in the process new principles for learning in the metaverse. These principles are an attempt to integrate current educational trends, immersive learning, and visual literacy, within a constructivist pedagogical framework. It is hoped that the proposed principles and our implementation via K-Cube VR can inspire future metaverse learning environments.

Keywords: Comprehending academic domain · Constructivism · Immersive learning · Visual literacy · Metaverse learning principles

1 Introduction

It has been shown that almost half of the students may become confused once they enter university - and almost a third may experience confusion about their plans for course enrollment [1]. Students need to plan their courses throughout their few years in college, often before they have a top-down grasp of their disciplines of choice. Moreover, they need to plan their careers and choose course plans that support such choices. This forward planning is not a trivial thing to do, and is particularly difficult for a typical student who has yet to acquire a panoramic knowledge in the academic programme on which they have enrolled. It has been suggested in [2] that, due to the scarcity of information, students' "planning" is mainly driven by herd mentality.

Understanding an academic domain is not an easy task, even for experts. An academic domain is abstract, or rather a collection of related academic concepts, which more than often are ideas that have complex dependencies and relationships. Therefore, understanding an academic domain requires extensive experience to organise these concepts and summarise their relationships [3], which can be difficult for students. At the university level, it is common to try to inform the students about the purpose of a course by providing a programme description; this description is likely to be insufficient as it often contains a list of keywords and learning outcomes only, and the students will still have to struggle with the fact that they might not have a good understanding of those keywords and descriptions. As such, there is a need to aid students in comprehending an academic domain to benefit their studies.

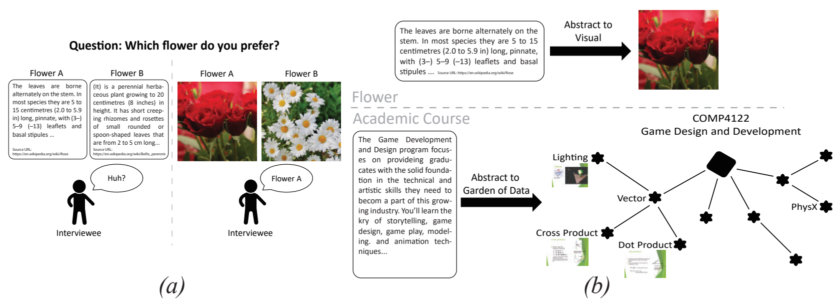

Fig. 1. *(a)* Visual representations can be more effective than textual descriptions. *(b)* We hypothesize abstract concepts can be converted into more intuitive representations. Some descriptive texts are from Wikipedia.

If textual description is insufficient in communicating the nature of an academic course, it may be the case that it is a medium of expression which is not optimal. To illustrate this modality issue, let us consider a hypothetical scenario where we need to decide which flower we prefer (Fig. 1*a*). If we were to ask a random person which flower s/he prefers, it may well be the case that s/he will be better able to answer it given images rather than textual description. To represent knowledge, it is important to consider which mode of representation is best suited for the task [4]. It is from this trail of thought that we hypothesize that there exists a more ideal and intuitive representation for an abstract entity such as an academic domain (Fig. 1*b*). This intuition drives us in our development of **K-Cube VR** [33]. Empowered by an interactive 3D knowledge graph (KG) in virtual reality (VR), we hope to represent the academic domain as a *garden of data* where the user can interact with academic concepts, akin to a flower in a garden.

To provide a theoretical backbone for our work, we explore several educational trends in this paper. With the advent of various extended reality (XR) technologies, *immersive learning* (IL) has become a popular topic in academia [7]. Most of the work captivates XR's ability to provide an immersive environment that can simulate realistic or reality-like scenarios for students' practices for an array of disciplines [8]. There are also discussions on learning abstract concepts with VR [9]. *Visual literacy* (VL) is referring to the person's ability to understand or communicate via visual information [5]. Educators in scientific domains may particularly concern themselves with visual literacy as visual frameworks have been shown to improve students' understanding of course materials [6]. Finally, *constructivism* is an important theory that many educators are well-versed in. It is the focus of our theoretical discussion because it is an epistemology, or a theory on the nature of knowledge. By understanding how people learn and hold knowledge in their minds, we hope to be able to develop a metaverse experience on academic knowledge that aids students' comprehension. Together, these educational ideas provide K-Cube VR with a solid theoretical backbone. Currently, it seems that IL and VL's research works are somewhat detached from a unified theoretical framework. They are, however, important concepts to learning in the metaverse. We address this issue by incorporating them into the same framework via a constructivist lens (Fig. 2). The proposed framework is utilized to discuss K-Cube VR's functionalities.

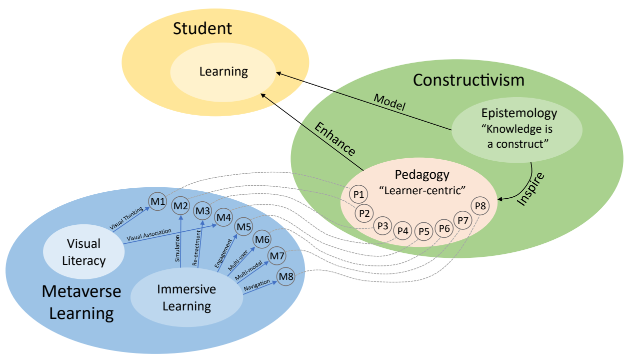

Fig. 2. The proposed metaverse learning principles are re-imaginations of pedagogical principles from constructivism in the context of IL and VL.

In summary, this paper aims to fill the gap in providing an effective means of presenting a more circumspect view of an academic domain to students. Our intuition is that abstraction can be expressed as a garden of data. Via a literature discussion, we show how educational trends such as IL and VL can be incorporated into constructivism. Via K-Cube VR, we also show a concrete example of how to manifest the proposed principles for metaverse learning. The paper's contributions are as follows: *(1) Incorporates immersive learning and visual literacy into constructivist pedagogy for building a metaverse learning framework; (2) Proposes eight metaverse learning principles; and (3) Demonstrates how these principles can be applied via K-Cube VR, a work-in-progress application.*

2 Constructivism

Constructivism is a term that has been adopted across a wide spectrum of disciplines, though its use in education is rooted in its place as an epistemological theory - an explanation for the nature of knowledge and how it is created. Limited by the scope of this paper, we limit ourselves to providing an overview of constructivism for enabling our theoretical discussion later.

In contrast to more classical learning theories which postulate that the world is full of static knowledge and that the process of learning is simply a matter of absorption, constructivism states that knowledge is an internal mental construction which requires learners to combine their past experiences with their present interactions with the environment where learning takes place to forge the building blocks of knowledge [15, 12]. Scholars commonly attribute the origins of this brand of constructivism to developmental psychologist Jean Piaget [12]. Piaget developed his "genetic epistemology" (an early form of constructivism) in the early twentieth century. He opined that "all structures are constructed", 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" [13, 14].

As time passed, the theory has been extended through a myriad of branching paths over the past century [16]. There are different scholarly views on the whole picture of this epistemology; however, a so-called *mild* constructivism has core ideas that are more or less agreed upon by constructionists across the board [12]. Further, it was not until the late 70s that it was re-discovered and adopted by educational academia [12]. This transfusion from epistemology to pedagogy, may have yet again led to heterogeneous views as a theory on learning cannot be directly translated into a theory on teaching. So, there are numerous proposals for constructivist principles on teaching, but most revolves around considering how the learner will handle and internalise the learning material. In addition, constructivism's main effect within education has been in awakening the notion that learning is a process that occurs when learners grapple with new concepts, not when instructors presents them.

Here, we adopt the pedagogical principles mostly compiled from the comprehensive literature reviews on constructivist teaching by Honebein [10] and Murphy [11]. According to them, constructivist teaching embodies these principles and goals (from [10] and [11]): (P1) Provide experience with the construction of knowledge; (P2) Provide experience in and appreciation for multiple solutions; (P3) Embed learning in a realistic and authentic context; (P4) Embed relevance in learning; (P5) Encourage ownership during learning; (P6) Embed social learning; (P7) Encourage usage of multiple representations, and; (P8) Emphasize exploration to encourage students to seek knowledge independently.

3 Immersive Learning and Visual Literacy

Immersive learning (IL) has been defined previously as a set of learning activities that are performed while the user's perceived environment is modified. In recent years, this effect is achieved often through the assistance of XR technologies - an iconic example of such technologies being the VR headset and handset. The immediate question of how much immersion is required to qualify as IL has resulted in scholars concluding that immersion is a spectrum: the user's subjective sense of "presence" [24], as well as an objective sense of "immersion" [25], can be measured quantitatively and used as continuous metrics to describe the aforementioned spectrum. IL has already been applied in many educational contexts. For instance, it has enhanced and extended classroom education at all levels [26, 27], raised awareness about social issues in a viscerally engaging way [28], and simulated natural disaster protocols for increased public safety [29]. Some scholars, like Jeremy Bailenson, have come up with heuristics like the DICE criteria (i.e., Dangerous, Impossible, Counterproductive, and Expensive) to form a basis for why and when IL ought to be used [30].

It seems that constructivism and IL are sometimes considered together due to a frequently undertaken, implicit assumption that IL is interactive by nature and, frequently, also by design; as such, there are studies that discuss how users interact with the constructed learning environment and synthesise information from it [31, 32]. We further this effort by integrating the properties of IL into constructivism more concretely, showing 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 [8] and engagement are some of the catalysts that are beneficial for constructivist learning.

Visual Literacy (VL) is an educational trend that studies how different visual media affect the quantity and quality of the user's comprehension. Different scholars have attempted to map the developments in VL, and these attempts more or less converge. For instance, Avgerinou [18, 19] concludes that there are four main aspects to VL, namely "visual perception", "visual language", "visual thinking", and "visual communication"; meanwhile, Felten offers fewer categories, such as the perspective that the VL can be separated into just the two subdomains of "visual cognition and perception" and "visual design" [5]. Regardless, they all consider users' interactions with the environment, as well as the recognition of a user's prior experience (in the form of their level of VL), which when taken together suggest that an argument could be made that these ideas - and therefore applications of VL - tend to align with the constructivist paradigm. VL has already been applied in educational settings as a "strategy for fostering creativity" in certain STEM fields [20]. Particularly interesting for our purpose is VL's ability to drive thinking and communication. We will later show how it can be part of constructivism's mental knowledge construction.

4 Constructivist Principles for Learning in Metaverse

From constructivism, scholars have derived pedagogical principles for educators to follow; and there are a large number of works attempting to implement a constructivist regime for students. However, according to some scholars, these regimes tend to stray from established principles of constructivism, and are limited in being mainly "learner-centric" [12].

With the advent of ever more frequent advances in XR and the metaverse, compounded by the increasing interest in their utilisation in education, we are seeing a growing tide of literature for IL. At the same time, VL gains exigency in this context as one of the strengths of XR lies in displaying visual information. Current works on IL and VL, however, do not usually anchor themselves into a greater pedagogical philosophy. Rather, they mainly investigate how their immediate methodology can assist students. We, therefore, advocate integrating IL and VL into a well-established and well-known framework such as constructivism concretely by showing how constructivist principles can manifest in the context of metaverse learning. The following are principles from Section 2 that are reformulated for the metaverse (Fig. 2).

(M1) **Knowledge as Visualised Construct:** One of the key ideas of constructivism is that knowledge is an internal mental construct. It is important to provide experience to students on its construction (P1). This can be addressed via a VL perspective as a visual vocabulary is believed to be able to help students think visually, and thus structurally [22].

(M2) **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 (P2). IL can provide an immersive simulation environment where the student can complete a task via different methods and thus, become more robust in their comprehension.

(M3) **Re-enact Daily Life Problem:** According to constructivism, as learners use their own experiences as building blocks for new knowledge, IL should re-enact daily life problems in an immersive simulation where the student is solving a problem they can associate with in real life (P3).

(M4) **Associate the Knowledge:** Extending upon the previous principle, for concepts that are more abstract, it is the case that learners may use their learned concepts to understand new knowledge (P4). Henceforth, the VL's visual vocabulary can show the association between concepts to help students understand how knowledge interweaves, and from there, build new understanding.

(M5) **Engage the Student in VR:** 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 initiative to learn [17].

(M6) **Multi-User Immersion:** Constructivism recommends that learning take place in relation with interpersonal interactions, whenever possible (P6). Meeting in a metaverse learning environment, the diverse experiences and indeed personalities of different learners, on the whole, oftentimes should offer a more dynamic and much richer set of stimuli for each learner.

(M7) **Multiple Modes of Content:** Constructivists advocate for the inclusion of multiple modes of representation to help with the mental construction of knowledge (P7). The best practice for the quantity, frequency, and presence of different types of multimedia becomes a rich ground for discourse in VR, which is more spatially adaptive to present content [34].

(M8) **Navigation of Knowledge:** Constructivism asserts that the user's exploratory interactions are important as a mechanism through which new knowledge is synthesised (P8). A good design seeks a balance of features allowing for the user's freedom to explore, as well as features designed to give guidance and structure to the user's exploration.

Not limiting ourselves to a theoretical discussion about a constructivist framework for learning in the metaverse, in the next section we provide concrete designs and implementations of how the principles can be applied.

5 K-Cube VR

K-Cube VR [33] is a garden of data, or a metaverse of knowledge, which aims to aid students in grasping an academic discipline via knowledge graph structure. Within this VR experience, students can visit each of the courses offered by a department and understand their content in the form of 3D graphs. Multimedia content is embedded for each course keyword to help the students understand the knowledge of the graph. A set of VR navigation functions are implemented to enable the exploration of the graph structure. Although our work uses KG that is manually annotated by experts in computer science, it is expected to be extended to a broad range of disciplines in the future. As the functionalities below show, K-Cube VR is designed based on the theoretical principles proposed in Section 4; hence, it demonstrates how the metaverse learning principles may manifest.

Knowledge Graph in VR. As presented in M1, a visual vocabulary can help the learner to understand knowledge as a construct. According to constructivism, knowledge is a mental construct that is organised. Therefore, KG is an ideal representation of knowledge. To help students better understand the discipline, we visualise KG as an immersive and interactive collection of virtual nodes which shows how academic concepts are formed and cross-related. To achieve so, there is a three-layer hierarchy formed by three levels of virtual nodes. A node, therefore, will belong to one of the three levels, disciplines (e.g. Computing), courses (e.g. Game Design and Development) and concepts (e.g. Vectors). The three-dimensional virtual space for visualisation (Fig 3), effectively, is partitioned into a discipline space where the student can see the courses and a course space where the student can see the concepts within a course. By visually organising knowledge in such a way and showing students the connections and hierarchy of concepts, it is expected to also help students to understand new concepts by seeing how they connect with concepts they already knew (M4).

Data Buddy. To better engage the student (M5), we introduced a data buddy as an aide to the students during their visit to the knowledge metaverse (Fig. 4*a*). It basically acts as a hub of information and can be called out by the learner when needed via a button. In addition, it is expected that students are usually not familiar with KG. The data buddy, therefore, also acts as a "data storyteller" who describes the meaning of KG elements (e.g. sub-graphs) to the students which helps with students' understanding (M7).

VR Navigation. As discussed in (M8), it is important to provide students with the tools to freely explore the learning environment. In order to enable

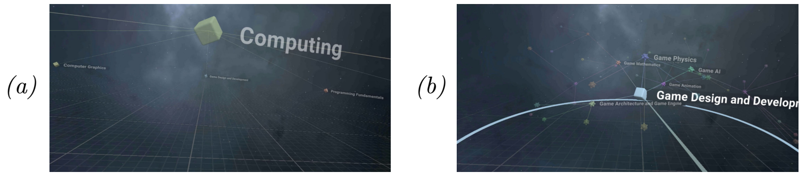

Fig. 3. The knowledge graph in K-Cube VR is partitioned into *(a)* a discipline space and *(b)* a course space.

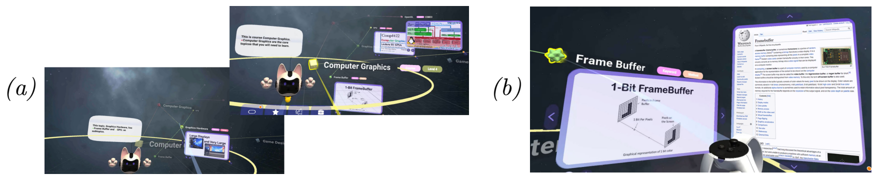

Fig. 4. *(a)* The data buddy is an aide to the student. It also acts as a data storyteller, describing the subgraph to the student. *(b)* The lecture notes and Wikipedia page are shown when a concept is selected.

the student to explore the KG, several operations are provided (Fig. 5): *(a)* spatial teleportation, *(b)* node teleportation *(c)* scaling, and *(d)* translation. *Spatial teleportation* allows the user to instantly teleport themselves to a new location; they can do so by pointing at a location on the plane. There may be cases, however, where the student simply wants to "go to" a node. *Node teleportation* fulfils this need by allowing the student to point at a node and teleport in front of it. Teleportation enables travelling of large distances without incurring motion sickness, but there is an issue of causing spatial disorientation [35]. *Scaling* allows the student to rescale the size of the knowledge graph. It is a useful navigational function when the graph is too large or too small from the student's perspective. *Translation* is similar to the two teleportation methods just described, but instead of the student moving toward a location, the student grabs the entire knowledge graph and moves it around.

Multi-source Content. As mentioned in the beginning, students do not have a strong background in the academic domain and, therefore, may have difficulties understanding the concepts. To help them understand the concepts in the knowledge graph, multimedia content is displayed when they are viewing a concept node. The current design provides two types of multimedia content for a particular node of concept: the related lecture notes and/or the corresponding Wikipedia page (Fig. 4*b*). The lecture notes can be "flipped" with the directional joystick handle (left-right) and the Wikipedia page can be read freely with the handle as well (up-down). By providing this duality of view on the concept, we hope it can help students understand that knowledge can be expressed from different perspectives and simultaneously help with their understanding (M7). In addition, the panel can be resized for viewing by dragging (Fig. 6).

Tags. It is also useful to show students that there are different categories of knowledge within a certain discipline. Currently, K-Cube VR mainly focuses

(a)
(b)
(c)
(d)

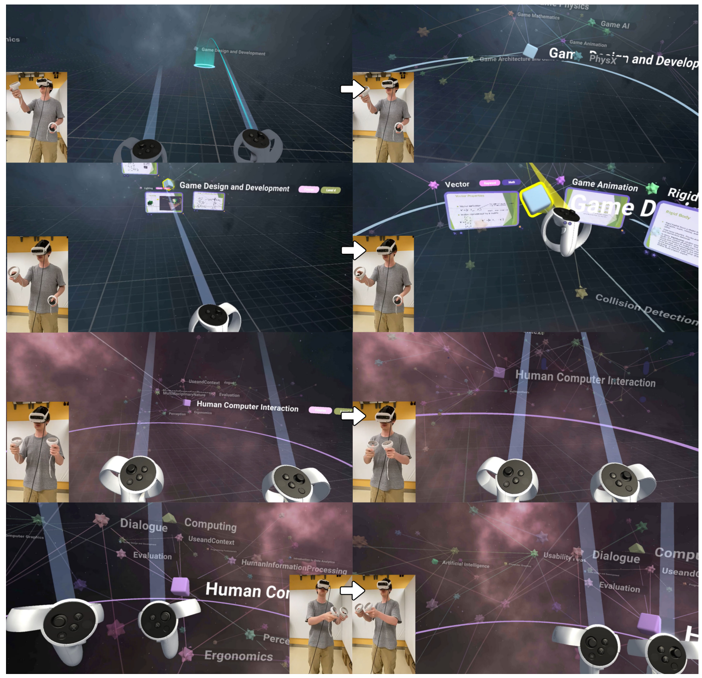

Fig. 5. K-Cube VR can be navigated by *(a)* spatial teleportation, *(b)* node teleportation, *(c)* scaling and *(d)* translation.

on computer science. We, therefore, briefly categorised the knowledge into, "concept", "algorithm", "method" and "math". The students will be able to use the tag board provided by the *data buddy* to visualise the nodes belonging to a tag (Fig. 7). It is hoped that this organisation further help students see knowledge in a clustered view (M7), and help them to locate concepts in a cluster (M8).

Study Room. In addition, we also provide a virtual study room for students to focus on the subgraph they are interested in (Fig. 8). The student can use a lasso to group select a collection of connected nodes. Once selected, the student will be brought to a virtual study room to help them focus on those concepts. We hope this is an engaging feature for students (M5).

K-Cube VR is a work-in-progress VR application that provides a preliminary view of a knowledge metaverse. To further complete the metaverse building, some important functionalities will be discussed in Section 6.

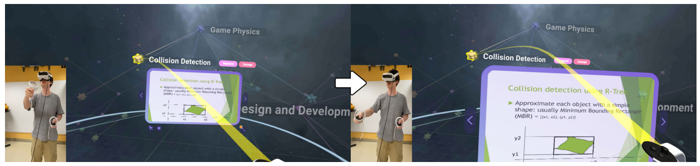

Fig. 6. The panel can be resized for viewing.

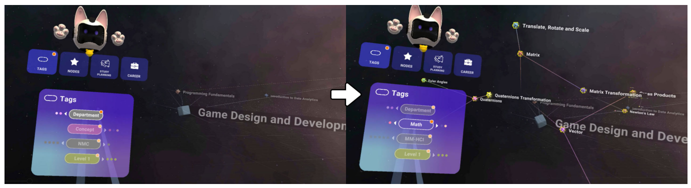

Fig. 7. Nodes are given tags such that they can be grouped and visualized.

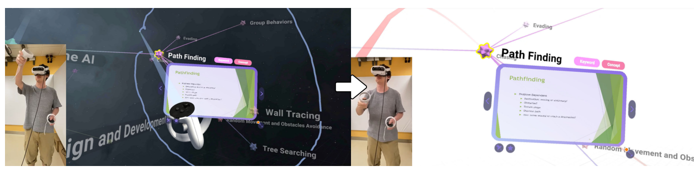

Fig. 8. Student can select multiple nodes at once and enter a study room.

6 Conclusion and Future Work

In this paper, we addressed how to aid students in their understanding of an academic domain, particularly its abstract concepts, in a metaverse environment. To provide a theoretical framework, IL and VL are introduced into a constructivist pedagogy, in which eight metaverse learning principles are formulated.

K-Cube VR is the application in which we show how to bring the metaverse learning theory to practice. To further complete our proposal for a metaverse of knowledge, however, there are some functionalities that need to be implemented as well. First, the social element is an important consideration for constructivists as they believe that learning is also driven by social interaction (M6). Therefore, an important function to implement in the future is to enable K-Cube VR to be explored by multiple students, and perhaps, with instructors in the same session. Second, we need to link the concepts with real problems that students may encounter more closely (M3). Ideally, K-Cube VR can also act as a hub that connects numerous pre-made simulations in the metaverse for learning the concepts (M2). In summary, we used K-Cube VR to show how to implement the proposed metaverse learning principles and it is hoped that these principles can inspire more metaverse learning applications in the future.

Acknowledgement

This work was supported in full by the Hong Kong Polytechnic University, Project of Strategic Importance (project number: P0036846). The authors thank Junnan Dong, Jerry C. K. Chan, Qinggang Zhang, Yaowei Wang, Wentao Li and Huachi Zhou for their useful discussions and feedback.

References

1. Li, P., Zhang, Z.P., Wang, Q.Q., Yan, J.K.: College Students' Psychological Crisis: Types, Factors and Countermeasures. In: Proc. of Intl. Conf. on Social Sci. & Higher Edu. 579–581 (2018)
2. Mendez, G., Galárraga, L., Chiluiza, K.: Showing Academic Performance Predictions during Term Planning: Effects on Students' Decisions, Behaviors, and Preferences. In: Proc. of CHI, 22:1–17 (2021)
3. Ethel, R.G., McMeniman, M.M.: Unlocking the Knowledge in Action of an Expert Practitioner. J. of Teacher Edu., 51(2), 87–101 (2000)
4. Willingham, D.T.: Ask the Cognitive Scientist Do Visual, Auditory, and Kinesthetic Learners Need Visual, Auditory, and Kinesthetic Instruction?. American Educator, 29(2), 31 (2005)
5. Felten, P.: Visual literacy. Change, 40(6), 60–64 (2008)
6. Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M., Wood, W.B: Scientific Teaching. Science, 304(5670), 521–522 (2004)
7. Dengel, A.: What Is Immersive Learning?. In: Proc. of Intl. Conf. of the Immersive Learning Research Network, 1–5. IEEE. (2022)
8. Akinola, Y.M., Agbonifo, O.C., Sarumi, O.A.: Virtual Reality as a Tool for Learning: The Past, Present & the Prospect. J. of Applied Learning and Teaching, 3(2), 51–58. (2020)
9. Dick, E.: The Promise of Immersive Learning: Augmented & Virtual Reality's Potential in Edu.. Info. Tech. & Inno. Foundation (2021). URL: https://itif.org/sites/default/files/2021-ar-vr-education.pdf (Accessed 01-08-2022)
10. Honebein, P.C.: Seven Goals for the Design of Constructivist Learning Env.. In: Wilson, B.G. (eds.) Constructivist Learning Env.: Case Studies in Instructional Design, 11–24, Educational Technology (1996)
11. Murphy, E.: Constructivism: From Philosophy to Practice. ERIC (1997). URL: https://eric.ed.gov/?id=ED444966 (Accessed 01-08-2022)
12. Sjøberg, S.: Constructivism and Learning. In: Baker, E, McGaw, B, Peterson, P (eds.) Intl. Encyclopedia of Edu., 3rd Ed., 485–490, Elsevier (2010)
13. Piaget, J.: Conversations Libres Avec Jean Piaget. Robert Laffont (1977)
14. Piaget, J.: Études Sociologiques. Librairie Droz (1997)
15. Von Glasersfeld, E.: Homage to Jean Piaget (1896–1982). The Irish J. of Psy., 18(3), 293-306 (1997)
16. Derry, S.J.: Beyond Symbolic Processing: Expanding Horizons for Educational Psy.. J. of Edu. Psy., 84(4), 413–418 (1992)
17. Coates, H.: The Value of Student Engagement for Higher Education Quality Assurance. Quality in Higher Education, 11(1), 25–36 (2005)
18. Avgerinou, M., Ericson, J.: A Review of the Concept of Visual Literacy. British J. of Educational Tech., 28(4), 280–291 (1997)

19. Avgerinou, M.D., Pettersson, R.: Toward a Cohesive Theory of Visual Literacy. J. of Visual Literacy, 30(2), 1–19 (2011)
20. Martin-Erro, A. Espinosa Escudero, M.M., Domínguez Somonte, M.: Visual Literacy as a Strategy for Fostering Creativity in Engineeering Edu.. In: Proc. of Intl. Tech., Edu., and Dev. Conf., (2016)
21. Lundy, A.D., Stephens, A.E.: Beyond the Literal: Teaching Visual Literacy in the 21^{st} Cent. Classroom. Procedia-Soc. & Behavioral Sci., 174(2015), 1057-1060 (2015)
22. Kędra, J., Žakevičiūtė, R.: Visual Literacy Practices in Higher Edu.: What, Why and How?. J. of Visual Literacy, 38(1-2), 1–7 (2019)
23. Radianti, J., Majchrzak, T., Fromm J. Wohlgenannt I.: A Systematic Review of Immersive Virtual Reality Applications for Higher Edu.: Design Elements, Lessons Learned, and Research Agenda. Computers & Edu., Elsevier (2020)
24. Witmer, B.G., Singer, M.J.: Measuring Presence in Virtual Env.: A Presence Questionnaire. Presence: Teleoperators and Virtual Env., 7(3), 225-240 (1998)
25. Slater, M., Wilbur, S.: A Framework for Immersive Virtual Env. (FIVE). Presence Teleoperators Virtual Env., 6(6), 603–616 (1997)
26. Piovesan, S.D., Passerino, L.M., Pereira, A.S.: Virtual Reality as a Tool in Edu.. In: Proc. of Intl. Conf. on Cognition and Exploratory Learning in Digital Age. 295–298 (2012)
27. Weymuth, T. Rehler, M.: Immersive Interactive Quantum Mechanics for Teaching and Learning Chem.. CHIMIA Intl. J. for Chem. 75(1-2), 45–49 (2021)
28. Markowitz, D.M. Bailenson, J.N.: Virtual Reality and the Psy. of Climate Change. Current Opinion in Psy. 42, 60–65 (2021)
29. Feng, Z., González, V.A., Amor, R., Spearpoint, M., Thomas, J., Sacks, R., Lovreglio, R., Cabrera-Guerrero, G: An Immersive Virtual Reality Serious Game to Enhance Earthquake Behavioral Responses and Post-earthquake Evacuation Preparedness in Buildings. Advanced Engineering Informatics 45. (2020)
30. Bailenson, J.: Experience on Demand: What Virtual Reality is, How It Works, and What It Can Do. Norton & Co (2018)
31. Aiello, P., D'elia, F., Di Tore, S., Sibilio, M.: A Constructivist Approach to Virtual Reality for Experiential Learning. E-Learning & Digital Media 9(3), 317–324 (2012)
32. Huang, H.M., Liaw, S.S.: An Analysis of Learners' Intentions Toward Virtual Reality Learning Based on Constructivist and Technology Acceptance Approaches. Intl. Review of Research in Open and Distributed Learning 19(1), 91–115 (2018)
33. Li, Q., Baciu, G., Cao, J., Huang, X., Li, R.C., Ng, P.H.F., Dong, J., Zhang, Q., Sin, Z.P.T., Wang, Y.: KCUBE: A Knowledge Graph Uni. Curriculum Framework for Student Advising and Career Planning. In: Proc. of Intl. Conf. on Blended Learning, 953–958 (2022)
34. AlSada, M., Nakajima, T.: Parallel Web Browsing in Tangible Augmented Reality Env.. In: Proc. of CHI EA, 953–958 (2015)
35. Rahimi, K., Banigan, C., Ragan, E.D.: Scene Transitions and Teleportation in Virtual Reality and the Implications for Spatial Awareness and Sickness. IEEE TVCG 26(6), 2273–2287 (2018)