Chapter 1
Introduction to 3D Immersive and Interactive Learning

Yiyu Cai, Chor Ter Tay and Boon Keong Ngo

Abstract The concept of 3D is not new. But never like today, 3D is rapidly entering our life. Using 3D for education is an innovative yet challenging work. This chapter introduces the concept of 3D Immersive and Interactive Learning, which is also called In-depth Learning. In particular, the enabling technologies and the supporting learning environments behind 3D Immersive and Interactive Learning are discussed. The relationship between In-depth Learning and other Learning Paradigms, such as Visual Learning, Simulation-based Learning, Constructivism Learning, and Engaged Learning, etc., are studied. This chapter also serves as an overall introduction to the whole book which presents several efforts in Singapore using 3D for In-depth Learning. The book covers a wide spectrum of education including Gifted Program, Normal (Technical) Stream, and Special Needs Education. The author(s) of each book chapter share their experiences from different angles on 3D In-depth Learning.

Keywords 3D • Immersive and Interactive Learning Environments • In-depth Learning, Science, Technology, Engineering, and Mathematics Education • Modeling, Simulation, Visualization, Interaction, User Interface • Virtual-reality • Assessment

Y. Cai (✉)
Nanyang Technological University, 50 Nanyang Avenue, North Spine, Block N3.2 Level 01 Room 08, Singapore 639798, Singapore
e-mail: myycai@ntu.edu.sg

C. T. Tay · B. K. Ngo
ZEPTH Pte Ltd, Singapore, Singapore
e-mail: chorter@zepth.com
B. K. Ngo
e-mail: boonkeong@zepth.com

Y. Cai (ed.), 3D Immersive and Interactive Learning, DOI: 10.1007/978-981-4021-90-6_1, © Springer Science+Business Media Singapore 2013
1.1 Introduction

In early 2003, Singapore was hit by an invisible invader—the coronavirus of the Severe Acute Respiratory Syndrome (SARS). The SARS outbreak was a timely reminder of the importance of education on virus infected communicable diseases. In Sept 2003, a one-year permanent exhibition—Convergence of Art, Science and Technology (CAST) was open to the public in the Singapore Art Museum. At the Gallery #10, a 3D Protein Roller-coaster was designed by the first author and his students [1, 2] aiming to have an innovative, intuitive, and interesting way for the public to understand SARS-related viruses and their protein structures (Fig. 1.1a). The exhibition received good response. Based on the same concept, a Bio X-game was designed and exhibited in Oct 2005 at the China Science and Technology Museum in Beijing (Fig. 1.1b). In this game, the protein ribbon structure was
modeled following the Chinese Great Wall. Players can learn molecular structures through riding on a virtual motorbike along the virtual Great Wall. In Dec 2005, Protein Rendition, the redesigned Bio X-game incorporating the protein sonification, was officially launched by Science Centre Singapore as part of the permanent Genome Exhibition [1, 3].

Around the same time, the high school section (also known as Chinese High School) of Hwa Chong Institution (HCI) in Singapore started to explore the use of 3D technology for learning applications. A small and simple Virtual-reality (VR) room was set up in the school in 2003 enabling the In-depth Learning through gaming. Students from the school formed a Special Interest Club. They organized workshops in their campus as well as in other schools to promote the concept of Learning Life Science through VR Gaming (Fig. 1.2a). River Valley High (RVH) is another Singapore school pioneering the use of 3D for In-depth Learning. A VR classroom was set up in the school in Feb 2007 (Fig. 1.2b). Since then, the school has organized various learning activities with their 3D learning environment. Mr Chow Ban Hoe from RVH will share his experience in Chap. 4 on 3D In-depth Learning in his school.

Fig. 1.2  a In-depth Learning in Chinese High School; and b In-depth Learning in River Valley High School
In 2008, the Singapore Ministry of Education (MOE) and Infocomm Development Authority (IDA) of Singapore launched the FutureSchools@Singapore [4] project. The initiative aims to develop a peak of excellence in an ability-driven education paradigm and to encourage innovation in schools:

These schools will not only enhance the diversity of educational offerings to cater to learners’ needs but also provide possible models for the seamless and pervasive integration of infocomm technology (ICT) that includes interactive & digital media (IDM). By harnessing ICT in the education sector through innovative pedagogies and flexible learning environments, schools will be able to achieve higher levels of engagement of their students who already have an infocomm-integrated lifestyle. Thus, students will be equipped with the essential skills to be effective workers and citizens in the globalised, digital workplace of the future.

Among the five FutureSchools@Singapore, Crescent Girls School (FS@CGS) and Hwa Chong Institution (FS@HCI) have set up their 3D Labs for In-depth Learning. CGS students attend Geography lessons in their Immersive and Interactive VR space. By virtual flying over the Victoria Falls in Africa, they learn map reading through gesturing with the aid of 3D technology (Fig. 1.3). At FS@
HCI, Mathematics and Biology teachers use their VR Lab to teach Trigonometry and Cell Biology. They also conduct pedagogical research on the impact of 3D for visual learning. Ms. Sandra Tan and Ms. Gwee Hwee Ngee from HCI will share their experiences in Chaps. 2 and 3 on 3D In-depth Learning of Biology and Mathematics, respectively. In Chap. 5, Mr. Joseph Tan et al. will share their interesting 3D sabbaticals conducted in HCI for students to learn Science, Technology, Engineering, and Mathematics (STEM) (Fig. 1.4).

Several other schools in Singapore have embarked on the journey of 3D for educational applications. The 3D Hub with the National Junior College (NJC) offers their students a platform to do various projects under their Science Training and Research (STaR) program. Figure 1.5a shows one of the projects—Sonar Terrestrial Observatory (STEREO). The same platform is also used to support their International Exchange Program (Fig. 1.5b) between NJC and Korea Science Academy (KSA). Mr. Nick Chan and his colleagues from NJC will share their story on 3D In-depth Learning in Chap. 6. In Chap. 7, Ms. Clara Wang and her team from Jurong West Secondary School will share their experience in teaching Nutrition with their Normal (Technical) stream using 3D Serious Games. Professor Noel Chia from the National Institute of Education and his collaborators will share in Chap. 8 their project on 3D virtual pink dolphins for special needs education.

In April 2011, the authors of this chapter organized a Symposium on 3D Learning in Singapore. This book is based on some of the selected papers presented at the symposium.

The remainder of the chapter is organized as follows. Section 1.2 discusses the enabling technologies for In-depth Learning in 3D Immersive and Interactive Environments. Section 1.3 investigates In-depth Learning with an emphasis on its relationship to Visual Learning, Simulation-based Learning, Engaged Learning, and Constructivism Learning. Section 1.4 gives the concluding remarks of this chapter.
1.2 Enabling Technologies for In-Depth Learning in 3D Immersive and Interactive Learning Environments

This section discusses the enabling technologies and 3D Learning Environments for In-depth Learning. In this study, 3D Immersive and Interactive Learning Environments are defined as Learning Spaces seamlessly integrated with 3D hardware, 3D software, 3D native learning contents, and pedagogy in the classroom or laboratory setting. Of specific interest, 3D modeling, 3D visualization, 3D interaction, and user interfaces are examined. These are four major enabling technologies for In-depth Learning in Immersive and Interactive Learning Environments (Fig. 1.6).

1.2.1 3D Modeling

3D modeling plays a fundamental role in creating objects with geometric shapes and physical behaviors in 3D spaces (Fig. 1.7). Rigid or deformable geometric
shapes can be typically represented by polygons (meshes) or freeform surfaces. Meshed geometry is a popular representation widely used today in animation and games. On the other hand, objects’ physical behaviors should be modeled as well for the purpose of illustrating their physical properties and dynamic change processes. The particle system is commonly used to simulate various physical phenomena like fluid, fire, etc.

Any objects in Immersive and Interactive Environments can be 3D modeled. The process of 3D modeling sometimes can be complicated. For instance, to model a protein molecule, one needs to deal with hundreds or even thousands of amino acids. Fidelity modeling, therefore, requires intensive domain knowledge about the context. It is highly important to create scientifically accurate models when describing and modeling learning content.

### 1.2.2 3D Visualization

Realistic visualization can assist students to better understand learning objects, concepts, and processes, especially the difficult ones. Visualization, however, is
traditionally 2D based. Objects or models in the 3D world of learning context are usually projected to 2D flat surfaces of printed textbook pages, blackboards, or projection screens. This projection could cause difficulty for students to figure out (or reconstruct) the disappeared third dimension of the original objects. Often, students are asked to use their imagination when dealing with 3D objects, or dynamic processes. This certainly poses challenges to many students (especially visual learners) when learning 3D based concepts using traditional 2D based learning paradigms.

Human beings live in the 3D world. Stereopsis is a human visual function. By processing a pair of images from the left and right eyes, the depth information can be perceived by viewers [5]. Based on the principles of human stereopsis, different types of 3D stereoscopic vision techniques (Fig. 1.8) are developed. Most of them synthesize the 3D perception by providing a pair of computer-generated images (one for the left eye and another for the right eye) with parallax information to produce the illusion of depth. While 3D modeling is a necessary task to develop Immersive and Interactive Environments, 3D visualization of 3D models is absolutely imperative in In-depth Learning. Stereoscopic visualization can produce realistic 3D effects’ value added to Visual Learning.

1.2.3 3D Interaction

Interactions exist ubiquitously in real worlds between objects, between objects and users, and between users. In 3D Immersive and Interactive Environments, physical objects in real worlds are mapped onto virtual objects in virtual worlds, and interactions between physical objects are mapped onto interactions between virtual objects. Interactions between users and physical objects in real worlds are mapped onto interactions between users and virtual objects in virtual worlds (Fig. 1.9). It is therefore crucial to have interactions implemented in Immersive and Interactive Learning Environments.
Benefiting from the advanced VR technology [5], users are able to experience or feel the interactions in virtual worlds. As such and ideally, in Immersive and Interactive Learning environments, students should be able to construct primitives when learning geometric shapes and feel the gravitation when learning Newton’s Law of Universal Gravitation.

1.2.4 User Interfaces

In VR, interactions can be implemented via suitable devices and user interfaces (Fig. 1.10). Graphic user interfaces (GUI) are most commonly used in software applications together with the mouse and keyboard. The Natural Interface (NI) is getting more and more popular especially after Microsoft successfully launched their Kinect product for gesture-based human–computer interaction. Tactile/Haptic User Interfaces (T/HUI) emphasize the experience of touch or force feedback. Today, several haptic or tactile devices such as phantom and cybergloves are commercially available in the market.

It is possible to have the above three major types of user interfaces integrated in a 3D Immersive and Interactive Learning Environment. Complementary to each other, GUI, NI, and/or T/HUI will provide different ways for human–computer interactions depending on different needs in different situations.
1.2.5 3D Immersive and Interactive Learning Environments

Figure 1.11 shows an overall view of 3D Immersive and Interactive Learning Environments which are an integration of hardware, software, pedagogy, and contents. Construction of Virtual Environments, however, has a number of technical challenges which are beyond the scope of this chapter and more information can be found in [5, 6]. Here, we will give a brief discussion of the architecture of the environments (Fig. 1.11).

From the hardware perspective, 3D Immersive and Interactive Learning Environments are typically equipped with high-end computers, high-performance graphic processing units (GPUs), high-end projection systems, various interactive devices, and network facilities. From the software perspective, the environments usually have suitable software for modeling and simulation, interaction, graphics and visualization, and optimization. Different contents should be designed and developed for teaching and learning purposes. Content development, however, is a lengthy and challenging process. Without pedagogy, an Immersive and Interactive Learning Environment is limited in its educational effectiveness. Therefore, it is crucial to integrate pedagogy into the design and implementation of the environments to ensure that they are not only technically advanced but also educational in nature.

![Diagram of 3D Immersive & Interactive Learning Environments](image)

**Fig. 1.11** 3D Immersive and Interactive Learning Environments
Introduction to 3D Immersive and Interactive Learning Environment will never be a Learning Environment. Enabled by 3D technology; In-depth Learning is built upon Visual Learning, Simulation-based Learning, Constructivist Learning, and Engaged Learning.

1.3 In-Depth Learning in Immersive and Interactive Environments

Section 1.3 discusses 3D Immersive and Interactive Learning Environments and the enabling technologies behind the environments. This section will investigate In-depth Learning in 3D Immersive and Interactive Environments more from the pedagogical point of view. Specifically, efforts will be made to study the use of Immersive and Interactive 3D technology to enhance Visual Learning, Simulation-based Learning, Constructivist Learning, and Engaged Learning (Fig. 1.12).

1.3.1 In-Depth Learning is 3D-Enabled Visual Learning

Electromagnetism (EM) is a difficult topic in Physics for many students to learn due to its invisibility of the EM field. In Geometry, the concept of skew lines (SL) and shortest distance of a pair of skew lines are hard for students to understand because of the limitation of visualization using the traditional blackboard or printed papers of textbooks as major teaching media.

In-depth Learning is 3D-enabled Visual Learning which is different from conventional Visual Learning where usually seeing is believing. In 3D Immersive and Interactive Environments, students can view objects in true 3D without heavily relying on “imagination”. With the third dimension easily available in immersive visualization, students can better understand difficult concepts like EM (Fig. 1.13a) and SL (Fig. 1.13b) avoiding imagination-caused spatial misunderstanding.

| 3D-enabled Visual Learning | 3D-enabled Simulation-based Learning | 3D-enabled Constructivist Learning | 3D-enabled Engaged Learning |
|---------------------------|-----------------------------------|---------------------------------|---------------------------|

Fig. 1.12 In-depth Learning versus Visual Learning/Simulation-based Learning/Constructivist Learning/Engaged Learning
1.3.2 In-Depth Learning is 3D-Enabled Simulation-Based Learning

River formation is a process that takes a long time to develop. It is difficult, if not impossible, to show the real and dynamic processes of river formation to students when they are learning these topics. Mitosis and meiosis are two different types of cell divisions that often confuse students when learning Cell Biology. It is practically infeasible to show these two dynamic and real processes of cell division when students are comparing them. Simulation offers an alternative solution by providing realistic and dynamic processes to mimic the real situation. In-depth Learning uses 3D-enabled simulation technology to enhance learning.
1.3.3 In-Depth Learning is 3D-Enabled Constructivist Learning

Constructivism [8–10] is popular today for designing computer-based learning environments and facilitating learning. Constructivism emphasizes that learning is an active process of constructing rather than acquiring knowledge and instruction is a process of supporting that construction rather than communicating knowledge.

Since 2007, a five day 3D sabbatical program is being conducted in HCI, thrice a year, which is open to all secondary students as an elective module. Based on the constructivism theory, the sabbatical is designed to allow students learning STEM in an active learning approach. Students are teamed up to do their project...
The learning topics covered so far in the sabbatical program (Fig. 1.15) include Star Warship, Formula One, Unmanned Aerial Vehicle, Domini Chain, 3D Avatar, etc. Students pick up basic skills of 3D Modeling and Simulation and 3D Visualization. Also, they develop innovative ideas related to STEM throughout their team projects. Instructors of the sabbatical serve as facilitators providing students necessary helps during the program.

1.3.4 In-Depth Learning is 3D-Enabled Engaged Learning

Engaged Learning is increasingly being adopted in classrooms. Engaged learners are responsible and self-regulated for their own learning [11]. Engaged learning is a joyful journey to engaged learners who can become passionate in learning and active in participating in challenging, authentic, multidisciplinary, and interdisciplinary learning activities.

In-depth Learning takes the advantage of 3D technology to engage students in their learning. Learning can become attractive and fun to students when they are immersed in VR environments: walking into the tiny cell world to learn the cellular structures and functions or feeling the force in a magnetic field. In-depth Learning seeks the sustainable growth of students’ learning interest and not just wow effects (Fig. 1.16).

Below are two reflections from RVH students after attending Cell Biology class at their daVinci Lab:

I feel invigorated and enthused by the 3D animated cells and it is indeed a very fulfilling experience for me. Now, I think I would like the Biology lessons more than ever as we dive deeper into the world of human biological cells. I would like other schools to have such special lessons too.

-Jadeline, RVH
It’s fun to see the 3D cells rather than 2D ones in photographs. The video has enhanced my understanding of cells and the lesson is engaging. Now I am keen to learn more and I hope there will be animation for other biology topics.

-Madeline, RVH

1.4 Conclusion

Traditional learning methods are sometimes criticized for their drawbacks in motivating the meaningful intellectual engagement. Always, students’ personal and academic development should be a central mission and hallmark of the school experience [12, 13]. The needs of the twenty-first Century Competencies in students have called for paradigm changes in teaching and learning. Engaged learning, active learning, and many other methods are being studied aiming to shift the emphasis of classroom activities from teacher-centric to student-centric, from passive rote memorization to active learning, critical and inventive thinking [14].

In-depth Learning is innovative to engage learners in 3D Immersive and Interactive Learning Environments backed by the state-of-the-art 3D technology including Fidelity Modeling, Stereographic Visualization, Real-time Interaction, and Human–computer User Interfaces. In-depth Learning is 3D-enabled Visual Learning, 3D-enabled Simulation-based Learning, 3D-enabled Constructivist Learning, and 3D-enabled Engaged Learning. Currently in Singapore, In-depth Learning is being implemented in some selected schools. Research on the effectiveness of In-depth Learning is being conducted in some of these schools. Assessment, especially formative assessment of using In-depth Learning, will be part of our future research.

According to Walter [7], “…. Einstein (he) could visualize how equations were reflected in realities — how the electromagnetic field equations discovered by James Clerk Maxwell, for example, would manifest themselves to a boy riding
alongside a light beam……”. While Einstein was unique in visualization of physics equations with the aid of his imagination and creativity, he would benefit from his earlier training in Visual Understanding with the School of Aarau before he was admitted to Zurich Polytechnic. The Visualized Thought Experiment he learned in this school would help make him the greatest physicist of his time. We hope this study on Immersive and Interactive 3D technology and the In-depth Learning method developed will become useful to students in their learning.

Acknowledgments The research work described in this book is partially supported by the National Research Foundation under the FutureSchools@Singapore Initiative and the Media Development Authority under the Media-in-Learning program.

References

1. Cai YY, Lu BF, Fan ZW, Chan CW, Lim KT, Qi L, Li L (2006) Proteins immersive games and music. Leonardo 39(2):135–137
2. Cai YY, Lu BF, Fan ZW, Indhumathi C, Lim KT, Chan CW, Jiang Y, Li L (2006) Bio-edutainment: learning life science through X gaming. Comput Graph 30(1):3–9
3. Shi XJ, Cai YY, Chan CW (2007) Electronic music for bio-molecules using short music phrases. Leonardo 40(2):137–141
4. FS@SG (2011) http://www.moe.gov.sg/media/press/2011/04/futureschoolssingapore-program.php. Accessed 20 May 2012
5. Vince J (1999) Virtual-reality. Addison-Wesley, Boston
6. Slater M, Steed A, Chrysanthou Y (2002) Computer graphics and virtual environments: from realism to real-time. Addison-Wesley, Boston
7. Isaacson W (2007) Einstein: his life and universe. Simon and Schuster, New York
8. Jonassen DH (1992) Evaluating constructivist learning. In: Duffy TM, Jonassen DH (eds) Constructivism and the technology of instruction: a conversation. Lawrence Erlbaum, Hillsdale
9. Jonassen DH, Peck KL, Wilson BG (1999) Learning with technology: a constructivist perspective. Prentice Hall, Englewood Cliffs
10. Merill MD (1992) Constructivism and instructional design. In: Duffy TM, Jonassen DH (eds) Constructivism and the technology of instruction: a conversation. Lawrence Erlbaum, Hillsdale
11. Jones B, Valdez G, Nowakowski J, Rasmussen C (1994) Designing learning and technology for educational reform. North Central Regional Educational Laboratory, Oak Brook
12. Smith KA, Sheppard SD, Johnson DW, Johnson RT (2005) Pedagogies of engagement: classroom-based practices. J Eng Educ 94(1):1–15
13. Light R (2001) Making the most of college. Harvard University Press, Cambridge
14. Felder RM, Brent R (1996) Navigating the bumpy road to student-centered instruction. Coll Teach 44(2):43–47