Yiyu Cai *Editor*

3D Immersive and Interactive Learning

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Editor
Yiyu Cai
Nanyang Technological University
Singapore

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Foreword

The introduction of the Internet into our conscious environment brought about a transformation in the way we communicate, making it possible to exchange information and acquire knowledge with little practical delays. While this represented a tremendous increase in efficiency, it was not until the advent of Web2.0 tools, which allowed for greater interactivity and enhanced online collaboration capability, that a new frontier was reached. Such tools fundamentally alter the ways in which we interact, and more importantly, they extend the connectivity for each individual to not just sources of knowledge, but also sources of expertise. A carefully structured connectivity sphere can then allow the individual to have access to a range of diverse and enriching interactions that was not possible before. When led by pedagogically sound designs, Web2.0 tools can be meaningfully weaved into teaching and learning environment to greatly enhance the educational journey of a learner.

3D visualization technology represents an important extension of interactive tools that has potentially inordinate applicability in a wide range of areas. Over the past five decades, this technology has made significant progress, particularly in bringing about accurate visualization of concepts that are difficult to verbalize. These include the illustration of the structures of macromolecules and the simulation of the life cycles of stars and galaxies. The use of the technology enables the learner to immerse in an environment that allows for learning through an increased range of sensory experience, which can potentially deepen understanding.

While there is much to be done in effectively using 3D visualization technology for teaching and learning, this book reports on a good range of efforts toward this end. It presents the collaborative efforts from researchers and practitioners in designing 3D native content for different subject learning, setting up of 3D environments for visual learning, conducting curriculum-based 3D classroom teaching, as well as nurturing students' learning interests and curiosity through 3D innovative co-curriculum research activities. Prof. Cai, the editor of this book with over 20 years of research experience in computer graphics, visualization and virtual-reality, has put together a commendable set of findings from a wide variety of work in using 3D visualization for teaching and learning. Such efforts are invaluable toward building a greater understanding of the educational use of such technologies. It is my pleasure to congratulate the editors and researchers represented in this book for adding on to our collective wisdom.

Dr. Horn Mun Cheah
Educational Technology Division
Ministry of Education
Singapore

Contents

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

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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

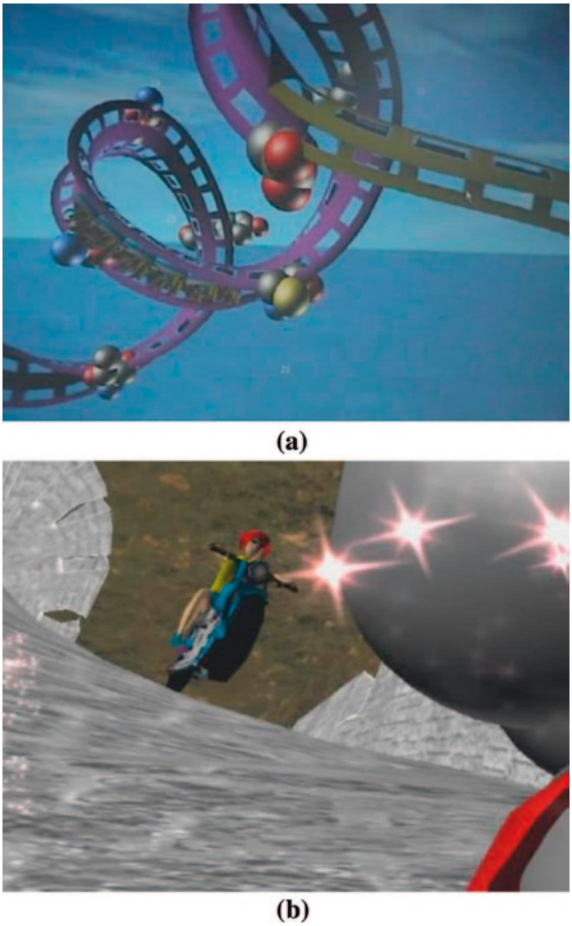


Fig. 1.1 Interactive and Immersive 3D Visualization: **a** a protein roller coaster; and **b** a protein X-game

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.

(b)

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@

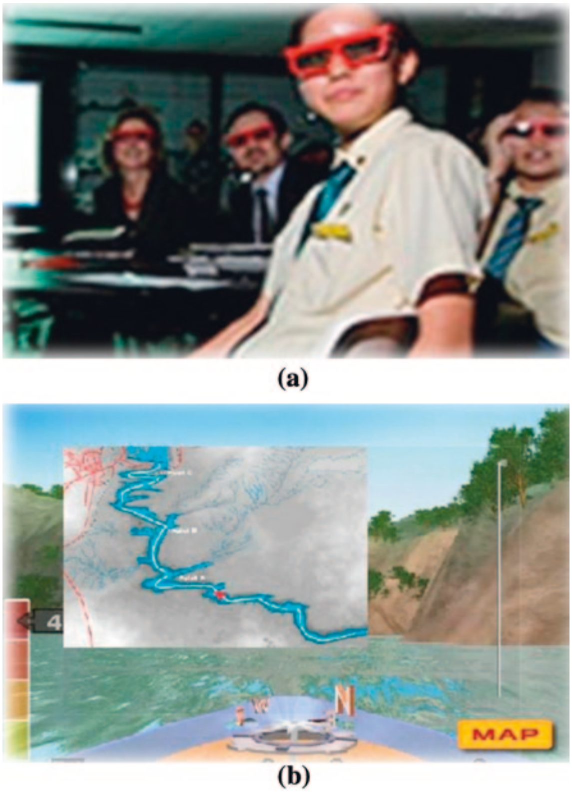


Fig. 1.3 In-depth Learning in FS@CGS: **a** the CGS's Immersive and Interactive VR space; and **b** learning victoria fall and map reading in the VR space

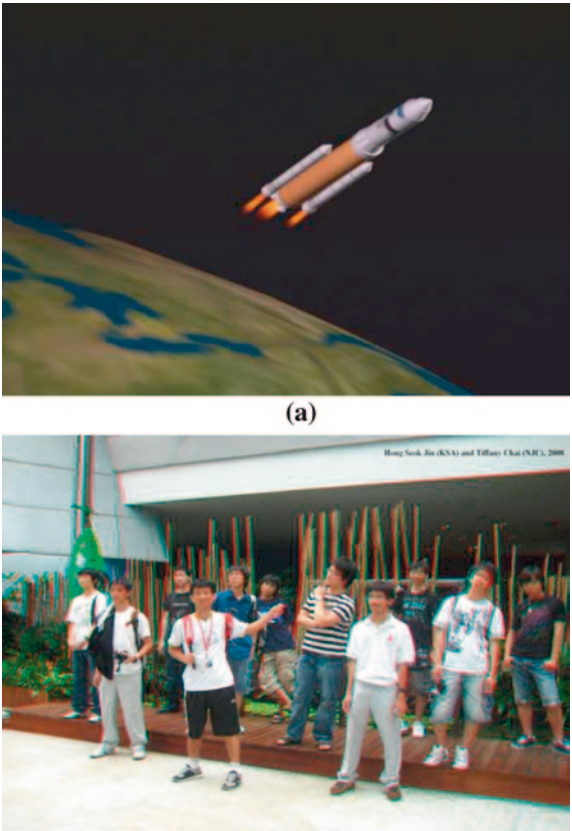
HCI, Mathematics and Biology teachers use their VR Lab to teach Trigonometry and Cell Biology. They also conduct pedagogical research on the impact of 3D for visual learning. Ms. Sandra Tan and Ms. Gwee Hwee Ngee from HCI will share their experiences in Chaps. 2 and 3 on 3D In-depth Learning of Biology 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.

Fig. 1.4 FS@HCI uses their VR lab for In-depth Learning of STEM



(a)

(b)

Fig. 1.5 In-depth Learning in NJC: **a** the research project STEREO; and **b** the NJC-KSA international exchange program

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

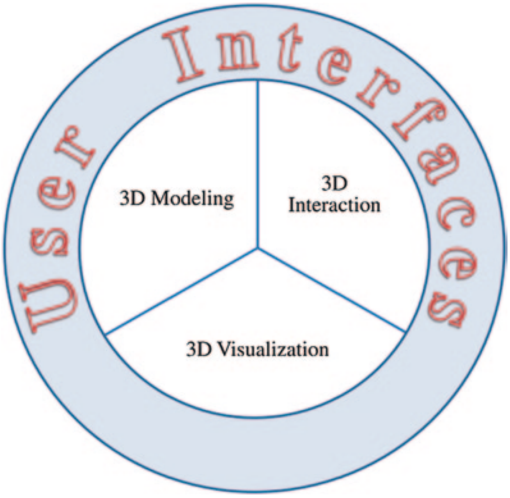


Fig. 1.6 Enabling technologies for In-depth Learning

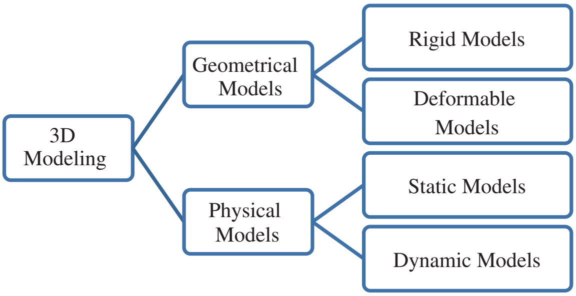


Fig. 1.7 3D modeling for In-depth Learning

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

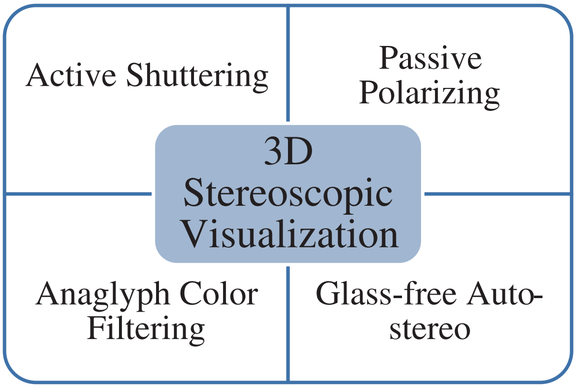


Fig. 1.8 Stereoscopic Visualization for In-depth Learning

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.

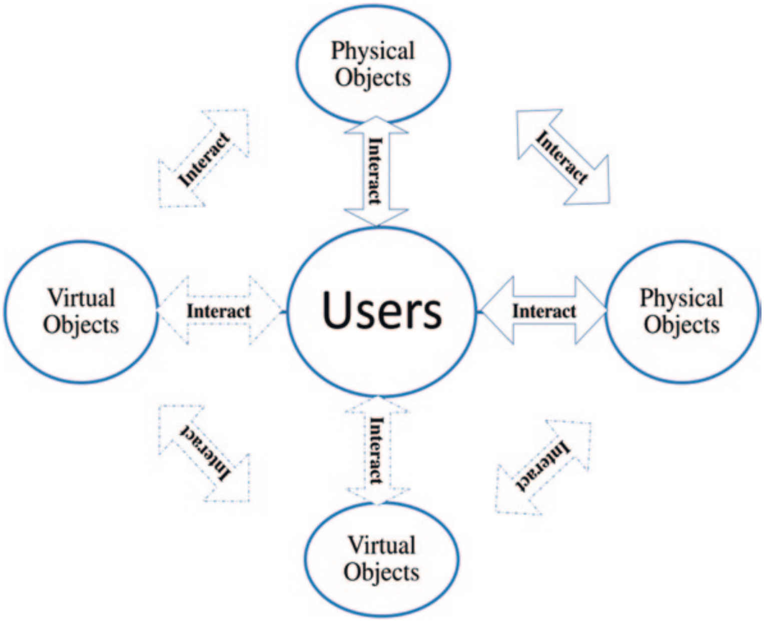


Fig. 1.9 Ubiquitous interactions for In-depth Learning

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.

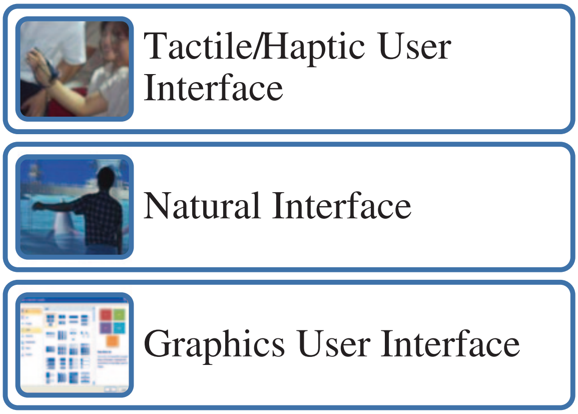


Fig. 1.10 User interfaces for In-depth Learning

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

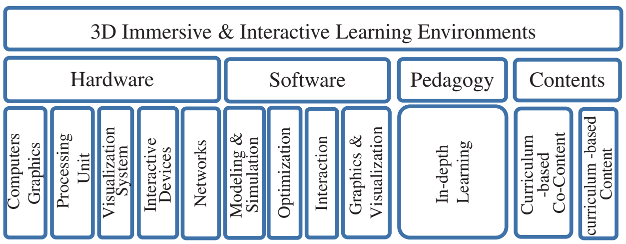


Fig. 1.11 3D Immersive and Interactive Learning Environments

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.

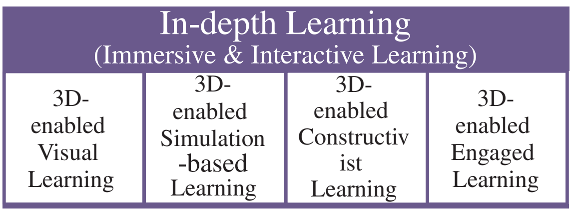


Fig. 1.12 In-depth Learning versus Visual Learning/Simulation-based Learning/Constructivist Learning/Engaged Learning

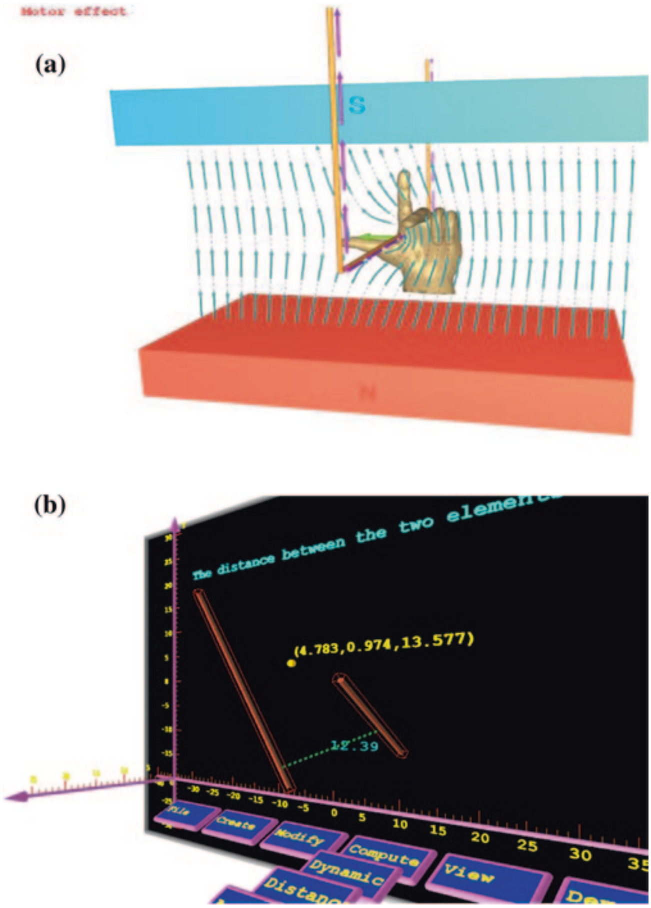


Fig. 1.13 **a** In-depth Learning of electromagnetism in Physics; and **b** In-depth Learning of shortest distance and skew lines in Trigonometry (Images courtesy of ZEPTH, CGS and HCI)

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.

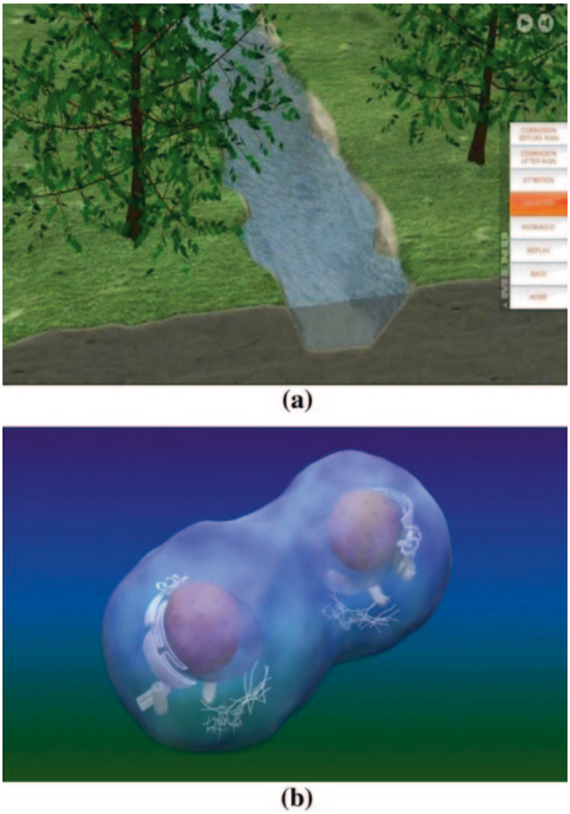


Fig. 1.14 **a** In-depth Learning of river formation; and **b** In-depth Learning of cell division (Images courtesy of ZEPTH, CGS and HCI)

Students can immerse them under water to observe the process of river formation (Fig. 1.14a), or immerse them inside virtual cells to observe the process of cell division (Fig. 1.14b).

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

Fig. 1.15 In-depth Learning of Formula One Design (Images courtesy of ZEPTH and HCI)

work. 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

Fig. 1.16 In-depth Learning of biology in daVinci lab @ RVH (images courtesy of ZEPTH and 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.

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Chapter 2
Use of Virtual-Reality in Teaching and Learning Molecular Biology

Sandra Tan and Russell Waugh

Abstract The teaching of Molecular Biology in secondary schools suffers from student disengagement and lack of suitable resources to help students master this novel area of their curriculum. The result is frustration and incomprehension by the students. Visualization is critical for the learning of Molecular Biology. While the traditional classroom uses diagrams, models, and other tools to accommodate visual-spatial learners, these tools are insufficient to represent the cellular and molecular dynamics elucidated by current research and presented in the modern biology classroom. Several works have recommended the use of simulation-based learning environments. This chapter describes the design considerations in formulating an approach to help students "see" DNA, proteins, and cellular structures in three-dimensional space. The experimental study and intervention described leverage on novel computer-based virtual-reality technologies to help students understand the three-dimensional structures and the molecular interactions between them that enable function. Results indicate significant increases in Molecular Biology achievement in male students. Focus group interviews reveal that, prior to this intervention, students relied heavily on memorization, and the visualization exercises helped to clarify understanding while increasing interest and engagement. The results of this study recommend the use of technology in the teaching and learning of Molecular Biology, especially for male students in Singapore.

Keywords Virtual-reality • Visual learning • Visualization • Molecular biology

S. Tan (✉)
Hwa Chong Institution, Singapore, Singapore
e-mail: sandra@hc.edu.sg

R. Waugh
University of Western Australia, Crawley, Australia
e-mail: russell.waugh@uwa.edu.au

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2.1 Introduction

The impetus for the present study on students' conceptions of Molecular Biology stems from recent changes to biology education in Singapore. Singapore's education system has been fundamentally driven by the needs of economic development [7, 13]. The most recent thrust to emerge has been the emphasis on life science research [4], a change that has percolated down from the tertiary institutions to junior college and high school curricula. The pace and depth of such changes, however, have caused the atmosphere in a Molecular Biology classroom to be one of disorientation, frustration, and resultantly incomprehension by students.

In this chapter, a research to investigate a solution to this problem is described. The study involved participants from several secondary schools in Singapore. They underwent a series of visualization exercises lessons in Molecular Biology. The research is conducted to explore whether the visualization exercises serve to increase participants' achievement in Molecular Biology, and the attendant skills that are important for understanding the subject.

The present study is also a project under the FutureSchools@Singapore initiative, as part of the Ministry of Education's Third Master plan for ICT in Education (2009–2014). The FutureSchools projects explore expanding learning possibilities, with Web-based and virtual learning environments that allow teacher–student interaction, online assessments, and monitoring of students' progress. Web 2.0 technologies, such as Wikis, video sharing, and Instant Messaging can expand the horizons of learning, allowing students to collaborate on projects among themselves as well as with peers from across the globe. The use of technology in schools, however, has not been objectively measured for effectiveness. In October 2011, a news story highlighted how executives working in technology companies such as Google and Microsoft were opting for traditional schools which eschewed technology; the view was that traditional schools allowed students to "experience" in a developmentally appropriate way [10]. A commentary in the local newspapers [12] also cited several cases of lack of assessment of technology use in the classroom, and even quoted a local teacher who discussed implementation of IT for its own sake without consideration for learning goals. Clearly, there is a need to objectively evaluate technology use in its different modes for specific teaching contexts, to address the concerns of various stakeholders in education.

2.2 The Research Design

2.2.1 Use of ICT

The design and use of visualization exercises on an ICT platform in the present study is informed by several empirical evidences and by the characteristics of today's students.

For example, in a study involving first-year medical students learning by virtual-reality (VR) experiences, Gutierrez et al. [11] described a positive effect of VR simulation on learning, as reflected by improvements in prescribed knowledge structures. More importantly, improvements demonstrated by the group given head-mounted display sets—where the three-dimensional (3D) visual experience was much more intense—were almost twice as large as the group relying only on computer screens in a partially immersive VR environment, and close to "expert" levels. Likewise, Barry et al. [5] described how the use of VR for exercise increased interest and engagement and increased the incidence of "flow", or energized focus, for reluctant exercise participants. Such positive reports of achievement and engagement provide a compelling suggestion for the use of simulation in Molecular Biology education.

Most previous studies to elucidate students' conceptions of specific areas of science have utilized "pencil-paper" illustrations [6] and diagnostic tests [17]. In light of the comfort of this generation of students as "technological natives" [18], the efficacy of visualization as a learning intervention for Molecular Biology might be enhanced if it occurs in a computer-based learning environment.

The use of ICT in the present study is in line with the characteristics of today's students. McHugh [14] discussed the characteristics of the new generation "iKid", whose whole life is dominated by cell phones, computers, and iPods and argued that the traditional teaching environment has lost touch with iKid's learning style. Similarly, Brevik [6] described the characteristics of these students as a generation experiencing "information overload". [19] Also agreed that there is discontinuity between learning styles of students today and the traditional classroom model. He named the students of today 'digital natives'—native "speakers" of the digital language of technology. While he made no reference to [14], [20] Implicitly agreed with both authors of this chapter and suggested that there have been recent trends in learning where students are living, learning, and working in a digital connected environment and students' learning styles are affected by daily exposure to technology. Technology, thus, plays a key role in the way students now learn and think. Recently, a new learning theory, connectivism [17], has emerged. This theory proposes learning to be a networked process. The connections of nodes of information are constantly evolving as students contribute to learning in collaborative online communities. This theory is relevant in explaining learning utilizing technology, where students are constantly exposed to text messaging, instant messaging, and other Web-based tools.

2.2.2 Consultation with Other Biology Teachers

A preliminary investigation was carried out to determine if visualization of Molecular Biology phenomenon was a prevalent problem among students.

Seven biology teachers from various schools in Singapore responded to a survey which sought their opinions on problems with students' conceptions of Molecular Biology. Some comments from teachers included, "students cannot 'see' how the different organelles in a cell function together…I have to show them several different pictures and hope they 'get it'" and "transcription and translation is a problem, since I have no way of showing students how the different molecules move in a complex".

Within the own classes of the first author of this chapter, the common complaint from students is that they are unable to "see" DNA and protein molecules on a 2D presentation, and thus cannot imagine the 3D structure and molecular interactions that enable cellular function. Most teachers and students welcomed the development of an addition resource that effectively communicated and represented the cellular and molecular dynamics of a cell, but also wondered if the use of such tools might lead to excessive investment of curriculum time on these topics.

2.2.3 Research Question on Computer-Based Immersive VR Visualization Exercises

The main research question guiding this study is "What are the effects of computer-based three-dimensional Molecular Biology visualization exercises on Molecular Biology achievement?"

Molecular visualization has now become a powerful tool in the biology and chemistry classroom [9, 16, 21]. In particular, interactive simulation-based learning environments for biology have developed rapidly in recent years. However, attempts to locate suitable simulation software and courses targeted at preuniversity levels have been unsuccessful. It appears unreasonable that postgraduate students are expected to be able to "plug-in" and to use and develop simulation tools for research when they have not been exposed to them in an instructional setting. This study represents possibly the first efforts to modify the existing research-based 3D simulation software for biology instruction at the secondary school level.

A series of computer-based immersive visualization exercises were developed as a proposed solution to the problem of student being unable to "see" cellular and subcellular level entities. A total of three large-scale VR modules were conceptualized and developed: (1) Cell organelles; (2) Protein making; and (3) Nuclear division. A VR Lab was set up in Hwa Chong Institution (HCI) in Singapore to enable the study. The VR Lab is equipped with a high-end projection system which is supported by a high performance VR workstation and a high-end interactive device. After a one-time calibration, the system can be used for multiple purposes in teaching, students' projects, and demonstrations. This setup of stereographic immersive and interactive 3D environment enables students to do visual learning and simulation-based learning. The technical considerations of the VR Lab setup and the animation software are proprietary to Zepth Pte Ltd.

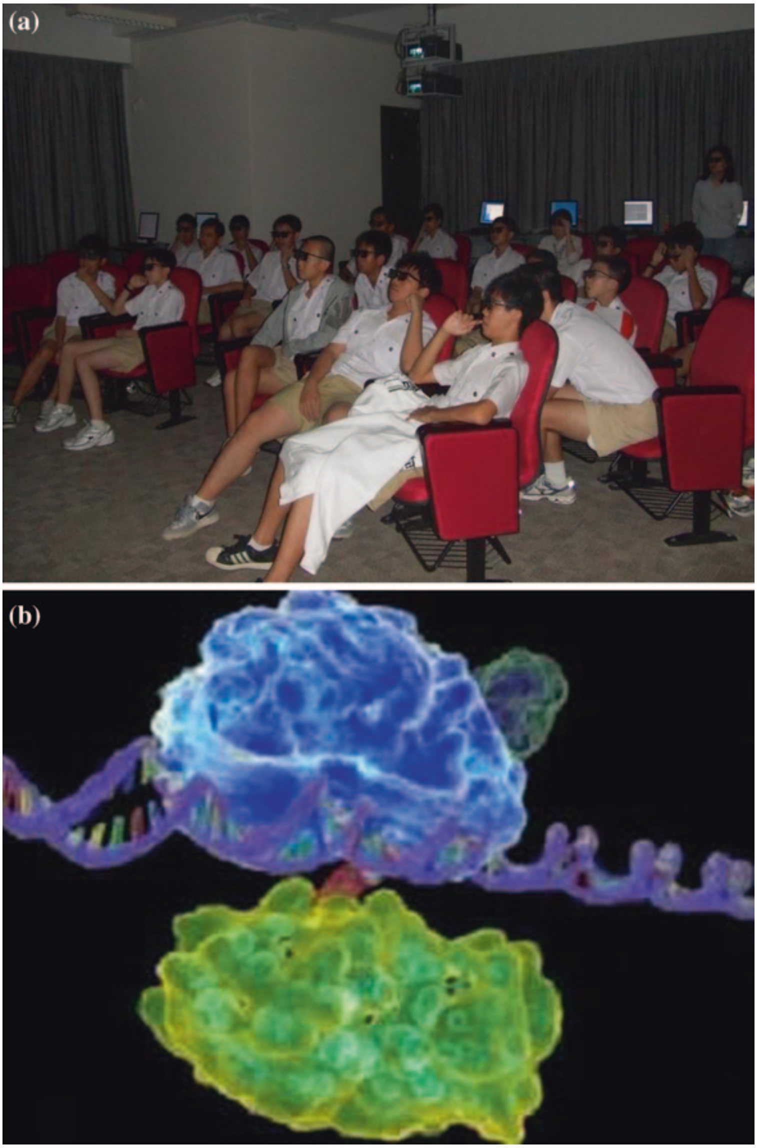


Fig. 2.1 **a** VR Lab @ HCI and **b** the 3D visualization of the protein transcription process in Molecular Biology

An example of a student handout is provided in Appendix I to illustrate how the visualization exercises were carried out.

Figure 2.1a shows the VR Lab @ HCI, and Fig. 2.1b shows the 3D visualization of the protein transcription process in Molecular Biology.

2.2.4 Implementation and Evaluation of Intervention

The proposed study involved Secondary 3 (Year 9) biology students from seven schools. These schools ranged from those admitting gifted and talented students to those whose students were average in ability. Purposive sampling was done so that participants had varying academic abilities but were fairly representative of Biology students in Singapore schools. Students in the experimental group were taught using the VR module to enhance visualization of Molecular Biology phenomenon, while students in the control group were taught the same content in the traditional way. Before and after the experiment, students in both groups did a survey on attitude and behavior toward Molecular Biology and a Molecular Biology achievement test.

In order to measure students' achievement in Molecular Biology, a questionnaire is specially formulated for the present study (Appendix II). It contains 10 two-step multiple choice items. The first part asks students about specific biological phenomenon, while the second part requires students to explain their answer based on key concepts. In this way, students who randomly "guess" the first answer will be found out in the second step. Each item is scored in two categories of either zero or one, depending whether participants demonstrate specific knowledge or core conceptual knowledge related to specific phenomenon; students who "guess" at the latter, but are unable to relate conceptual understanding with phenomenon are given zero scores. Such an approach increases precision when gaging students understanding.

Data were analyzed with the Rasch Unidimensional Measurement Model (RUMM 2030) computer program [2] using the Extended Logistic Model of Rasch [1]. Pretest items were scored in the same response categories to obtain a set of raw scores which were then allocated the equivalent Rasch linear measures from the posttest analysis. In this way, the pretest and posttest measures were fitted on the same linear scale, and thus can be validly compared. A two factorial analysis of covariance (two-way ANCOVA) allows determination of whether the main effects are independent of each other; that is, whether the two variables interact with each other. The two factors analyzed in the two-way ANCOVA are within-subjects factor (time), which is pretest versus posttest at two levels and between-subjects factor (treatment), which is teaching using the visualization exercises and software versus the traditional classroom method of "chalk and talk", also at two levels. A second two-way ANCOVA was also carried out to compare the pretest versus posttest scores of male and female students.

2.3 Results and Discussions

2.3.1 Summary of Rasch Analysis

Table 2.1 indicates that the item-person and person-item fit are good. The standardized fit residuals have a distribution with a mean near zero and a standard deviation

Table 2.1 Summary statistic, Person-item interaction

	Items		Persons	
	Location	Fit residual	Location	Fit residual
Mean	0.00	0.16	−0.31	−0.03
SD	0.95	1.05	1.14	0.63

near one, meaning that there is a good pattern of person and item responses consistent with a Rasch measurement model.

The Person separation index is an estimate of the true score variance among the participants and the estimated observed score variance using the estimates of their ability measures and the standard error of these measures [3]. The Person separation index is 0.73 and it is lower than the ideal of 0.9. It is an indicator that all the participant measures are not separated by more than their standard errors [3]. Based on this index, the achievement questionnaire can be improved by including some easy and difficult items to better target the high achieving participants.

Of the 20 items in the questionnaire, nine items measuring specific knowledge and nine items measuring conceptual understanding fit the measurement model with probabilities greater than 0.10 (except item 17). These are listed in Table 2.2, and their difficulties (locations) are presented, in order from easiest to hardest. Residuals represent the differences between the observed responses and the expected responses calculated from the Rasch measurement parameters. The residuals of each question fall within the standardized range of –2 to +2 (except item 1).

Item 15 is easiest whilst item 6 is reported to be most difficult. The items in the questionnaire that fit the Rasch model are a mix of both testing specific and conceptual knowledge in different topics of Molecular Biology. However, participants reported that the questions related to specific phenomenon (coded in green) were easier than questions probing conceptual understanding (coded in blue). This may be a reflection of current classroom pedagogy, and suggests that more needs to be done to help students in understanding and relating to “big ideas” and concepts in Molecular Biology.

2.3.2 Immersive VR Visualization Improved Achievement Scores

The measures for Molecular Biology achievement are displayed in graphical format separated by whether the intervention has been received (Fig. 2.2) and by gender (Fig. 2.3). These data are examined to determine the effects of the visualization exercises. The data are stratified according to gender and analyzed with ANOVA, showing $F(1, 245) = 7.54$, with $p = 0.006$. This means that males perform statistically significantly better than females in terms of achievement. Likewise, the mean experimental group measure is statistically significantly higher than the mean control group measure at posttest ($F(1, 245) = 7.54$, $p = 0.000$).

Table 2.2 Ordered difficulties for items in the molecular biology achievement questionnaire

Item	Location	Residual	Topic
15 (easiest)	−2.981	−0.499	Proteins and enzymes: digestion
7	−1.309	−0.089	Cell structure and function: organelles
1	−0.504	2.606	Cell structure: function-adaptation correlation
9	−0.420	−0.055	Cell structure and function: osmosis and diffusion
5	−0.250	1.591	Cell structure and function: organelles
11	−0.230	−0.699	Proteins and enzymes: nutrition
17	−0.226	1.859	Enzyme kinetics
13	0.099	1.126	Enzyme characteristics
19	0.181	−0.549	DNA: transcription, translation impacting cell function
8	0.287	0.392	Cell structure and function: organelles
4	0.335	0.306	Cell structure and function: transcription and translation
10	0.379	−0.236	Cell structure and function: osmosis and diffusion
2	0.463	−1.396	Cell structure: function-adaptation correlation
20	0.787	−0.285	DNA: transcription, translation impacting cell function
14	0.773	−1.113	Enzyme characteristics
12	0.858	−0.159	Proteins and enzymes: nutrition
18	0.872	−0.417	Enzymes kinetics
6 (hardest)	0.885	0.467	Cell structure and function: organelles

The items measuring specific knowledge are in green and the items measuring conceptual understanding are in blue

This indicated that the visualization exercises are effective in improving Molecular Biology achievement scores.

In order to ascertain that the results are not due to differential item functioning by gender, checks are carried out on whether the items work in the same way for male students as they do for female students. The item characteristic curves can be separated by gender and each item checked for differential item functioning. All items are found to show no statistically significant differential item functioning and an example is given for item 10 using ANOVA ($F(1, 7) = 0.12$, $p = 0.73$) in Fig. 2.4.

Tables 2.3, 2.4, and 2.5 give the two-way ANCOVA results of achievement scores and the interaction between the two independent variables, as indicated by "*", and their main effects displaying the sum of squares (Type III Sum of Squares), degree of freedom (*df*), *F* statistics (*F*), significance of the *F* statistics (sig.), and

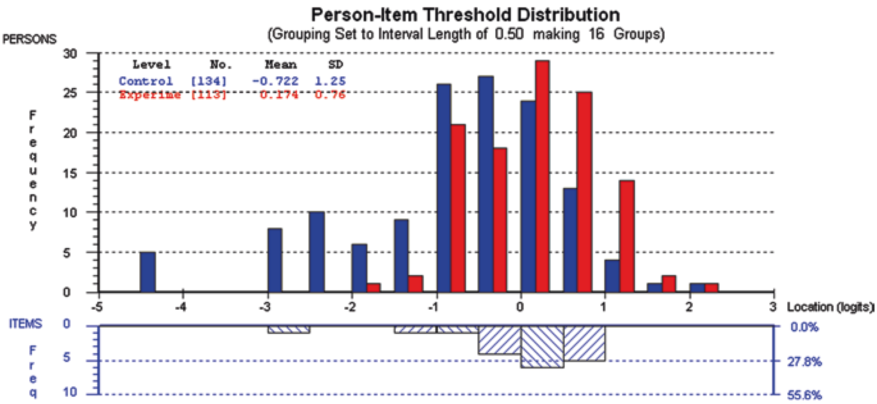


Fig. 2.2 Target graph by type for the Molecular Biology achievement questionnaire. For all Rasch measurements, the frequency of correct responses (*top*) is mapped against item difficulty (*bottom*)

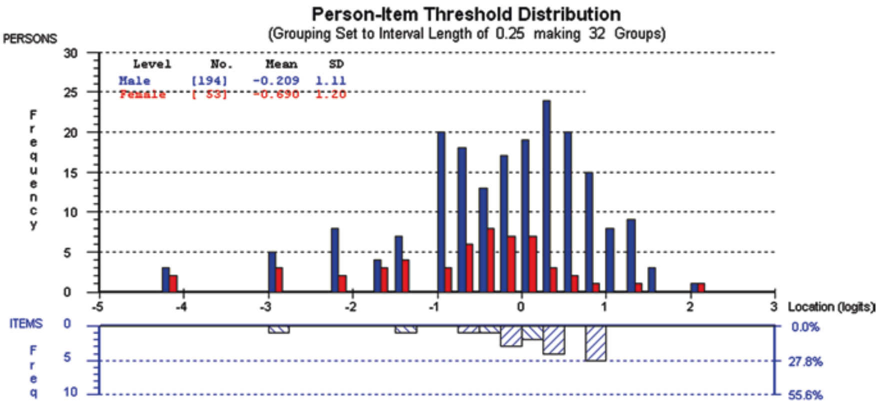


Fig. 2.3 Target graph by gender for the Molecular Biology achievement questionnaire

eta squared (Eta Squared) for each dependent variable. The eta squared is a measure of the effect size or magnitude of the effect. It describes the degree of association between the independent and dependent variable in terms of percentage. Figures 2.5, 2.6, and 2.7 shows changes in the mean measure of achievement at pretest and posttest in all participants, and in female and male participants, respectively.

Figure 2.5 show the differences in achievement scores between the control and experimental groups. There was a statistically significant difference in pretest and posttest achievement measures for the experimental group relative to the control group (Mean = –0.426 vs. –0.722) ($t = 1.937$, $df = 260$, $p = 0.02$). Additionally, the interaction effect reached statistical significance ($F = 3.54$, $df = 2$, $p = 0.03$). This means that the intervention effect of visualization in Molecular Biology resulted in significantly higher achievement measures for the experimental group overall.

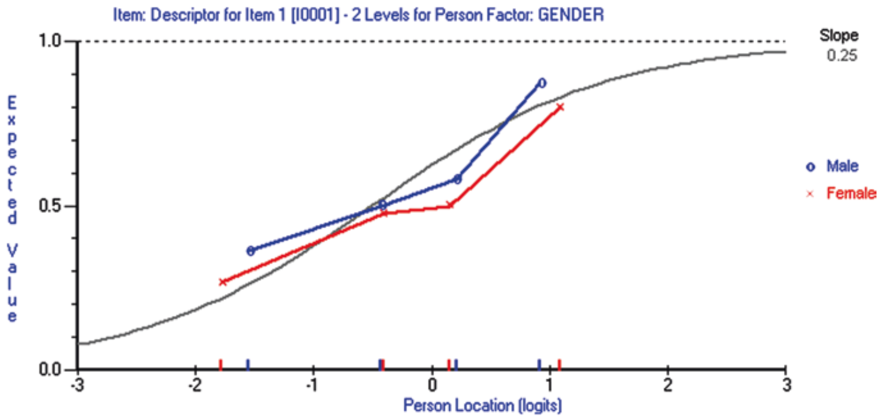


Fig. 2.4 Item characteristic curve with differential item functioning by gender for Molecular Biology achievement questionnaire item 10

Table 2.3 Two-way ANCOVA results of achievement measured in Logits in control and experimental groups

Source	Type III sum of squares	*df*	Mean square	*F*	Sig.	Eta squared
Corrected model	16.994[a]	2	8.50	12.99	0.00	1.03
Intercept	1.51	1	1.51	2.31	0.13	0.01
Group	0.03	1	0.13	0.15	0.83	0.00
Pre/Posttest	16.53	1	16.53	25.26	0.00	0.10
Group*Pre/Posttest	5.01	2	2.51	3.54	0.03	0.10
Error	148.49	227	0.65			
Total	167.10	230				
Corrected total	165.48	229				

[a] $R^2 = 0.103$ (Adjusted $R^2 = 0.95$)

Examination of pretest and posttest differences in achievement between genders yielded mixed results. Figure 2.6 indicates difference between female participants in the experimental and control groups, but the interaction effect did not reach statistical significance ($F = 0.10$, $df = 2$, $p = 0.90$). Similarly, Fig 2.7 shows that male participants in the experimental group maintained higher achievement measures than the control group, but this was due to the invention and the interaction effect which was statistically significant ($F = 4.93$, $df = 2$, $p = 0.01$). Therefore, while the interaction effects are not statistically significant in the case of female participants, the intervention for visualization in Molecular Biology produces improvement in male participants and overall in the study.

Table 2.4 Two-way ANCOVA results of achievement measured in Logits in female control and experimental groups

Source	Type III sum of squares	*df*	Mean square	*F*	Sig.	Eta squared
Corrected model	2.695[a]	2	1.35	1.97	0.15	0.09
Intercept	0.14	1	0.14	0.20	0.66	0.00
Group	0.04	1	0.91	0.55	0.82	0.00
Pre/Posttest	2.57	1	2.57	3.76	0.06	0.09
Group*Pre/Posttest	0.15	2	0.07	0.10	0.91	0.00
Error	25.99	38	0.68			
Total	28.82	41				
Corrected total	28.69	40				

[a] $R^2 = 0.094$ (Adjusted $R^2 = -0.046$)

Table 2.5 Two-way ANCOVA results of achievement measured in Logits in male control and experimental groups

Source	Type III sum of squares	*df*	Mean square	*F*	Sig.	Eta squared
Corrected model	13.26[a]	2	6.63	10.68	0.00	0.12
Intercept	0.01	1	0.01	0.03	0.87	0.00
Group	2.90	1	2.90	4.67	0.03	0.03
Pre/Posttest	2.57	1	2.57	3.76	0.06	0.09
Group*Pre/Posttest	11.04	2	11.04	17.78	0.00	0.01
Error	101.27	163	0.62			
Total	114.87	166				
Corrected total	114.53	165				

[a] $R^2 = 0.116$ (Adjusted $R^2 = 0.105$)

2.3.3 Immersive VR Visualization Increased Engagement, Interest, and Understanding

To better understand the improvements in scores, 26 male students were gathered for focused group interviews. The participants were asked about their perceptions of Molecular Biology before and after experiencing the visualization exercises. Four main themes were elucidated from the responses.

Theme 1: Prior to the study/exposure to VR elements, students found Molecular Biology difficult to understand and were intimidated by the subject.

There was almost unanimous agreement among students that Molecular Biology was difficult to grasp. These students noted their fear and anxiousness when first exposed to the subject. While their nervousness generally subsided over time, their difficulties in understanding the topics remained. Typical student comments were:

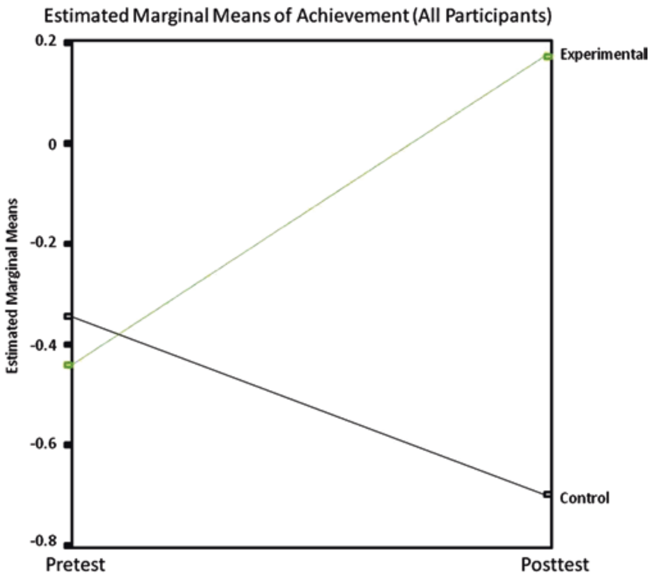


Fig. 2.5 Graph of estimated biology achievement mean scores in Logits against pretest versus posttest for experimental and control group participants

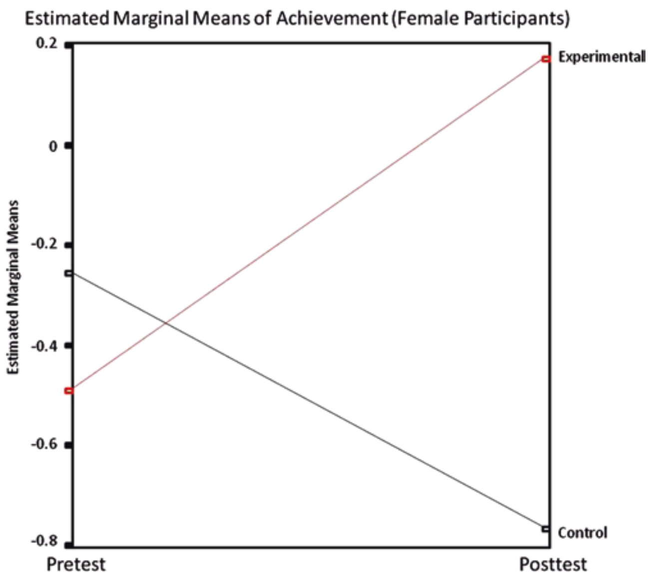


Fig. 2.6 Graph of estimated biology achievement mean scores in Logits against pretest versus posttest for female experimental and control group participants

The topic of Molecular Biology was a daunting one which was extremely hard to understand clearly, due to the complexity of the organelles and the interactions between them.

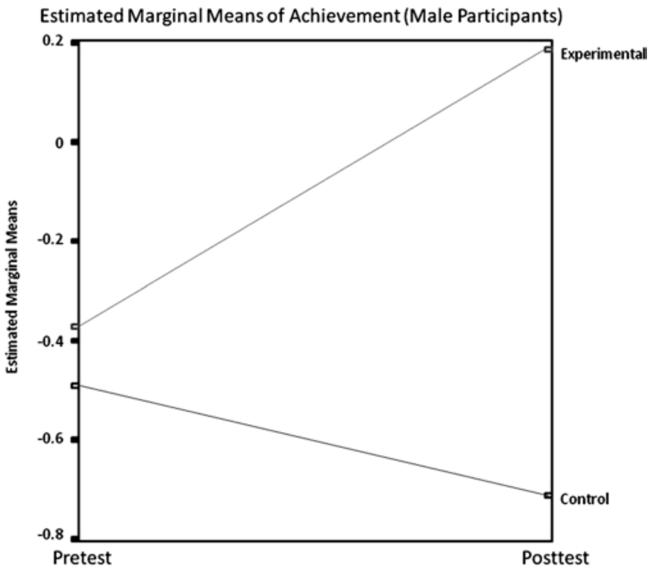


Fig. 2.7 Graph of estimated biology achievement mean scores in Logits against pretest versus posttest for Male experimental and control group participants

> Initially, Molecular Biology had been an exceptionally intimidating topic to me. We are often presented with static images that provided us with a limited understanding of how various organelles within a cell operates and looks like. Furthermore, dozens of organelles are revealed at once, without any former introduction of any sort, resulting in a rigorous experience for students to grasp after a single lecture.

This fear and lack of understanding even led students to give up the subject altogether in Junior College.

> I thought that Molecular Biology was dry and complicated. I did not wish to study Molecular Biology in a more in-depth manner as it was far too complicated.
> I thought that Molecular Biology was especially confusing and disturbingly hard to understand. Especially because this topic would become more in depth in Junior College, I decided to drop biology and instead continue with the other 2 Sciences, Physics and Chemistry.

Theme 2: Prior to the study/exposure to visualization exercises, students found Molecular Biology abstract.

The most important reason cited for a lack of understanding was the degree of abstraction found in topics in Molecular Biology. The inability to see, hear, and touch phenomenon at the molecular level contributed difficulty in comprehension. Several students went further to cite the disjuncture between what images presented and verbal explanation in class as a major contributor to their confusion. One student admitted that he had to rely on “imagination” to help him guess the phenomenon. Students described their lack of understanding in the following comments:

> Molecular Biology seemed to be an abstract idea… I could not really grasp. Even though clear pictures were used in PowerPoints to illustrate various concepts, it was hard to clearly figure out the interactions between various entities such as the cell organelles.
> Molecular Biology is a topic which students do not come into contact with often in life, thus it is an abstract topic.
> Molecular Biology is an abstract topic that is hard to grasp, thus making it a little boring. The Powerpoint slides and available pictures also didn't really help me understand it fully, thus studying it for exams was rather tedious as I didn't really understand fully what I was studying.
> It was difficult to conceptualize at times. As a result, one had to rely on one's own imagination to learn, ending up where some might learn it wrongly.

Theme 3: Prior to the study/exposure to visualization exercises, students relied on rote memorization to cope with Molecular Biology.

To help themselves do well, in spite of their lack of understanding, students relied heavily on rote memorization as means to score in tests. Almost all students believed that memorization was necessary; even students of higher ability regarded it as the most effective way to do well.

> The content of Molecular Biology lessons involved a lot of memorization work. Furthermore there were numerous terms which had to be learnt, which made things even more complicated.
> Studying Molecular Biology heavily relies on a student's memorization skills.
> The fact that we were only taught via pictures did not help but only made me memorize the steps that happened in things like transcription and translation without any understanding so that I would get high marks when answering test and examination questions.
> I had some decent understanding of Molecular, but I never tried to visualize it so it was mostly just memorizing terms and the way it works.

The role of memorization was deemed as crucial, superseding understanding, and even in very able students. This finding points to an area of concern for curriculum managers and a need to re-examine pedagogy in schools. While traditional achievement tests indicate that schools in Singapore are generally doing well in (MOE 2008), students' comments indicate that tests need to be more closely scrutinized for questions that stress application of concepts and that more resources need to be developed to help student conceptually in the Molecular Biology.

Theme 4: Students agreed that visualization was crucial to understanding Molecular Biology.

Prior to the visualization exercises, students indicated a cognitive gap between what was explained and what was shown to them in class.

> These perceptions were a result of a lack of resources in thoroughly explaining the concepts to the students. Visually, I was very lost, and could not imagine what it was like at a molecular level.
> Molecular Biology was a fairly interesting topic, however I found the topic hard to understand from the perspective of a visual learner such as myself, where diagrams alone could not accurately depict the processes. Molecular Biology occurs on a minute scale, and hence the methods of depiction used are either inaccurate or static, which may hamper our capability to comprehend the topics taught.
> Powerpoint slides featuring various pictures of molecular related stuff was not sufficient for me to fully comprehend the complexity of Molecular Biology, leading to many

> misconceptions. Many of the Powerpoint slides are also presented in text, forcing me to speculate images (of molecules), which was fairly tough at times, and this leads to my slow progress on topics that touch on Molecular Biology.

After viewing the animations and participating in the visualization exercises, student cited increased interest and engagement in the subject. Increased focus also resulted in better understanding about concepts learnt previously in class.

> The most enjoyable about the visualization exercises were the dynamic 3D molecular structures that kept me captivated. Static images that I used to study with in the past had little or no appeal at all.
>
> I enjoyed the interesting and unique method of presenting the idea of Molecular Biology.
>
> I liked the fact that the visualization exercises made it very interesting and exciting to students like me. We not only understand the topic better, but the visualization exercises helped me look forward to learning more, because learning has been made easier in this field and even more interesting.
>
> The close-up of Molecular Biology through 3D visualization exercises was most useful as they provided me with a clearer understanding of molecular structures.
>
> The visualization exercises were most useful in that the animations allowed me to better grasp the processes taught step-by-step, as compared to static visuals or 2D animations by viewing the processes from a new perspective. For instance, on the flu virus life cycle, one can better visualize the entry of virus DNA/RNA into the cell and specifically how they replicate via the creation of cell DNA/RNA in the cell nucleus, as well as the proteins formed on the cell membrane. This helped me to grasp various aspects of Molecular Biology, especially processes such as transcription and translation, as these occur on minute scales, and the topics can be difficult to grasp without the aid of animations.

The improved cognition of Molecular Biology processes resulted in greater interest and engagement. This was important in generating better learning attitudes and behaviors, which in turn translated to greater achievement in male students.

2.4 Conclusion

The data for the Molecular Biology Achievement Questionnaire are analyzed with the Rasch Unidimensional Model (RUMM2030) computer program [2]. The results show that the item-person and person-item fit were good. The Person separation index, measured 0.73, indicates reasonable reliability and consistency of the measures along the scale of achievement.

The visualization exercises are effective in improving Molecular Biology achievement scores; students in the experimental group perform statistically significant better than the control group students in achievement at posttest. And while there is statistically no significant differential item functioning by gender, male participants perform statistically significantly better than females in achievement at posttest.

Items testing specific knowledge were easier than the items testing conceptual understanding, indicating that students found it hard to translate their awareness of phenomenon into corresponding general concepts. This is a potential area of improvement for teaching and learning Molecular Biology in the Singapore context in which academic program managers should look into.

Interviews with students indicate that the visualization exercises helped to increase understanding whilst stimulating interest and engagement. All these serve to bring about significant improvements in achievement scores. Prior to these exercises, students relied heavily on rote memorization to do well in tests. The possibility of achievement without deep learning is an area of concern for all teachers and worth examination by administrators in their own schools.

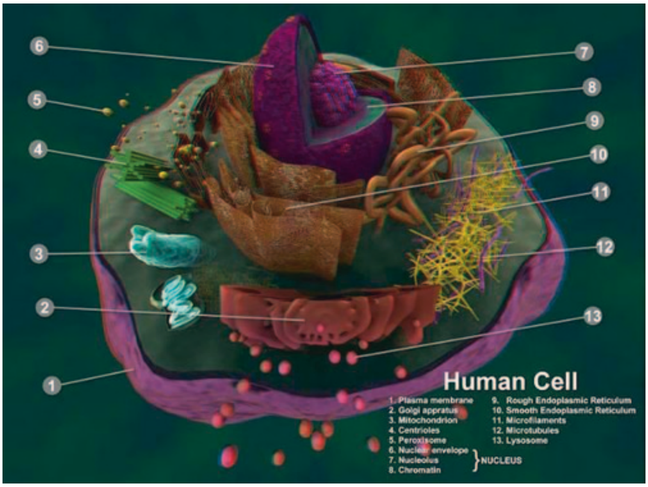
Overall, the visualization exercises conceptualized, initiated, and evaluated indicate that these are useful to promote understanding of achievement in Molecular Biology. It is hoped that the resultant developmental framework and lesson plans may serve as a guide to teachers looking to improve teaching and learning Molecular Biology in secondary schools in Singapore, as well as other aspects of teaching and learning that are heavily dependent on visual elements.

Acknowledgments This project is supported by the National Research Foundation under the FutureSchools@Singapore Initiative.

This work would not have been possible without the support of many friends and colleagues at Hwa Chong Institution. Special thanks were given to Professor YY Cai from NTU, and Mr. Ngo Boon Keong from Zepth Pte Ltd.

Appendix I: Sample Student Handout for Visualization Exercise

Cell Organelles, Functions, and Interactions



In this exercise, you will "look at" the various structures of a human cell to gain a better understanding of its function. You will also compare and contrast the plant and animal cells.

Get together in your groups after each segment to answer the questions below.

Your group should also sketch your ideas and questions on the blank sketch pad on the walls and use the plasticine provided to build and refine your cell models.

Cell Membrane

1. What are the components of the cell membrane?
2. Why are the different components arranged this way? What interactions enable them to stay in place?

Nucleus

1. What is the function of the nucleus?
2. How is the nuclear membrane different from the cell membrane?

Endoplasmic Reticulum

1. What is the function of the endoplasmic reticulum?
2. What are the differences between the smooth and rough endoplasmic reticulum?
3. How are the nuclear membrane and the endoplasmic reticulum connected?

Golgi Body

1. What is the function of the Golgi body?
2. There is a polarity to the Golgi. What are the differences between the “cis” and “trans” faces of Golgi?
3. How is the Golgi membrane connected to the cell membrane?

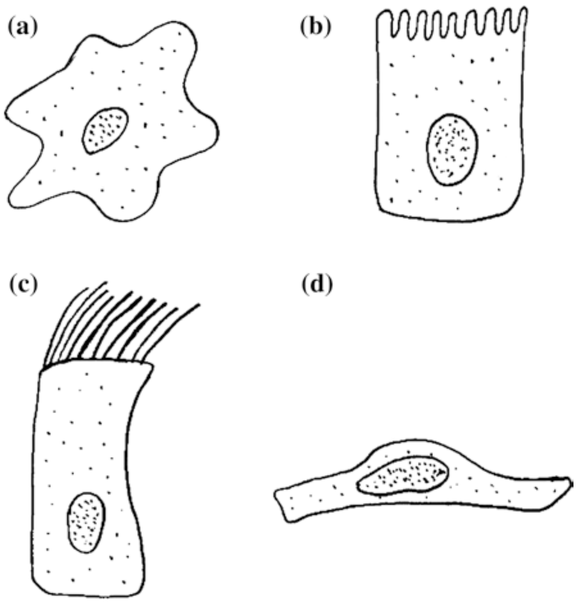
Plant Cell versus Animal Cell

1. What are the differences between a plant and an animal cell?
2. What properties does the cellulose cell wall confer on a plant cell?
3. How is the central vacuole different from the vacuoles of an animal cell?

Appendix II: Biology Achievement Questionnaire

Each multiple choice question is divided into two parts.
The first part asks a specific question related to Molecular Biology.
The second part asks for an explanation of the answer given in the first part.
In each case, choose the most appropriate answer from the options given.
You will score 1 mark if you get the first part of the question correct.
You will score 2 marks if you get both parts of the question correct.
You will not score any marks if you get the second part correct but the first part wrong.

1. Which of the following cells is adapted to absorb nutrients efficiently?



Explanation:

A increased surface area increases rate of active transport
B increased surface area to volume ratio increases rate of active transport
C increased surface area increases rate of diffusion
D increased surface area to volume ratio increases rate of diffusion

2. Radioactive amino acids were introduced into the cytoplasm of human pancreatic cells that were actively synthesizing protein. The cells were maintained for 3 days in a culture medium.

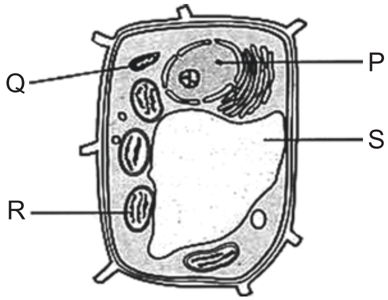
In which of the following would radioactivity not be detected?

A nucleus
B endoplasmic reticulum
C Golgi body
D ribosomes

Explanation:

A the nucleus controls the activity of a cell
B the endoplasmic reticulum is involved in protein synthesis
C the endomembrane system allows organelles to share lipids
D the Golgi body packages proteins

3. The figure below shows the organelles in a plant cell. Which of the following statements about the labeled parts is incorrect?



A P controls the activities in the cell
B Q is the site of aerobic respiration
C R is the site of synthesis of energy
D S stores food

Explanation:

A the nucleus controls the activity of a cell
B the mitochondria oxidize glucose to produce ATP
C the chloroplasts reduce carbon dioxide to produce glucose
D the vacuole stores metabolic waste

4. An amoeba had its nucleus removed. For several days it continued to move and feed, but it did not reproduce. An intact amoeba reproduced twice in that time. What conclusions do you draw from this experiment about the role of the nucleus in the amoeba?

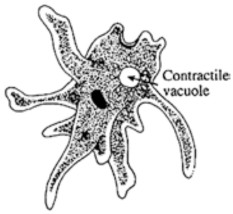
A The nucleus is necessary for cell division
B The nucleus regulates the activity of the cell

C The nucleus is the only part of the cell that contained DNA
D The nucleus is necessary for the cell to grow

Explanation:

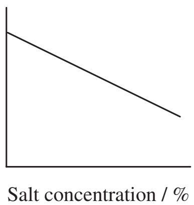
A DNA is necessary for reproduction
B DNA is necessary for growth
C DNA is necessary for movement
D DNA is necessary for feeding

5. *Amoeba proteus* is a small aquatic organism which lives in freshwater ponds. It has a contractile vacuole which slowly increases in size, and then suddenly contracts and vanishes when the liquid within it is being forced out of the amoeba into the surrounding water. This helps in the removal of excess water from the amoeba. Soon, the vacuole reappears and again slowly increases in size, and the process is repeated.

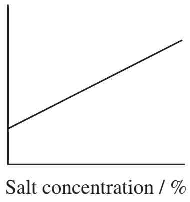


Which of the following graphs show a correct relationship between the frequency at which the vacuole is emptied and the concentration of salt in the surrounding water?

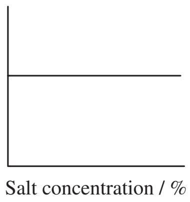
A Frequency of contraction/min^{-1}



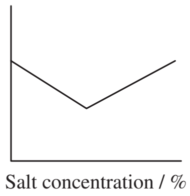
B Frequency of contraction/min^{-1}



C Frequency of contraction/min^{-1}



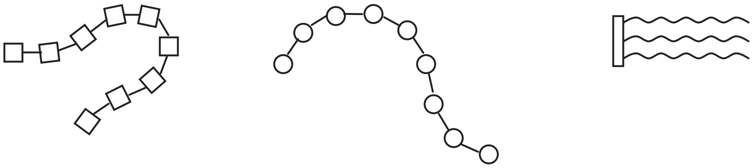
D Frequency of contraction/min^{-1}



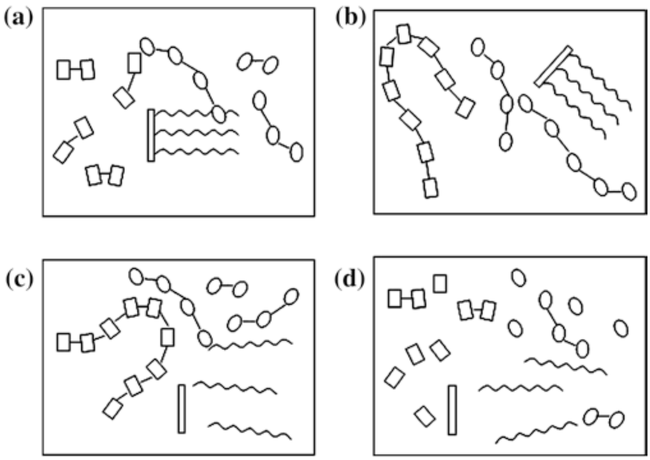
Explanation

A water moves down a concentration gradient
B water moves down a potential gradient
C water moves against a concentration gradient
D water moves against a potential gradient

6. The diagrams below represent molecules of starch, protein, and fat.



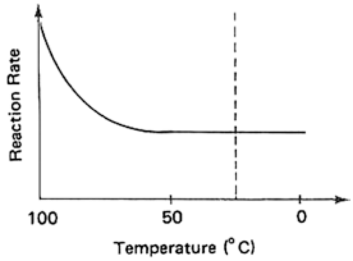
Which of the following mixture of molecules will be found in the stomach?

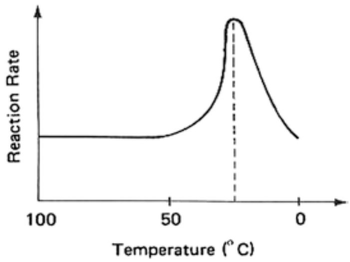


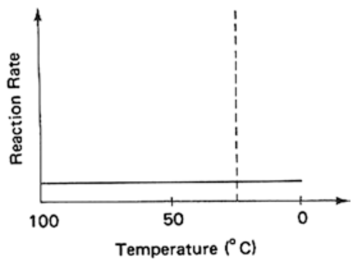
Explanation:

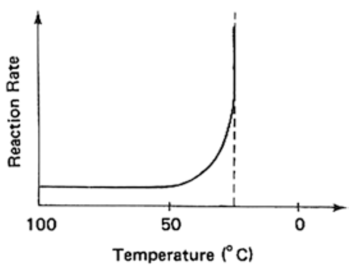
A starch is digested in the mouth
B protein is digested in the stomach
C fats are digested in the mouth
D fats are digested in the stomach

7 Which of the following graphs show the rate of reaction when a hot mixture of proteins and pepsins are cooled down from 100 to 0 °C?


Reaction Rate
100
50
0
Temperature (°C)


Reaction Rate
100
50
0
Temperature (°C)

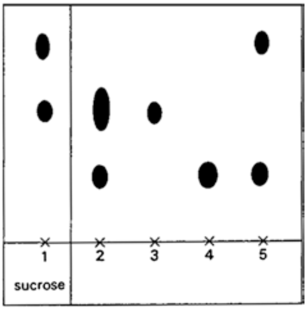

Reaction Rate
100
50
0
Temperature (°C)


Reaction Rate
100
50
0
Temperature (°C)

Explanation:

A inactivation is reversible
B denaturation is reversible
C inactivation is irreversible
D denaturation is irreversible

8 Five disaccharides were hydrolyzed with dilute acid, and the purified products were separated by 1D chromatography. The final chromatogram is shown in the diagram.



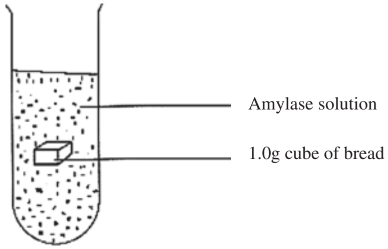
If spot 1 represents the products obtained from the hydrolysis of sucrose, which one of the following indicates the results obtained from the hydrolysis of lactose and maltose?

	Lactose	Maltose
A	2	3
B	2	4
C	5	2
D	5	3

Explanation:

A both lactose and maltose are diasaccharides
B maltose is made up of glucose
C lactose is digested by lactase
D maltose is digested by maltase

9 The figure below shows an experiment to investigate the action of amylase on a 1.0 g cube of bread. After 20 min at 25 °C, 0.4 g of bread was digested.



If the experiment was repeated at a temperature of 35 °C, which of the following would be obtained?

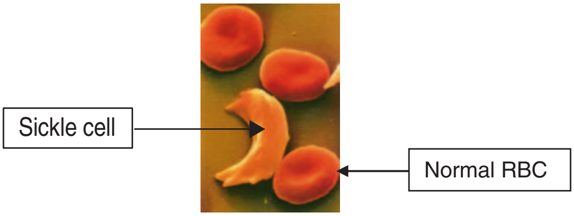
A 0.2 g of starch
B 0.8 g of starch
C 0.2 g of maltose
D 0.8 g of maltose

Explanation:

A enzyme activity is dependent on temperature
B enzyme activity is dependent on pH
C enzyme activity is dependent on substrate concentration
D enzyme activity is dependent on enzyme concentration

10 Sickle cell anemia is a defect due to a mutation of the hemoglobin gene. People with such condition often suffer from breathlessness. The mutation leads to the production of a wrong type of polypeptide chain which makes up hemoglobin. In the abnormal polypeptide chain, the sixth amino acid is replaced by valine.

The result of such mutant is that the shape of the red blood cells is changed.



Explain how this change would affect the ability of the red blood cell to serve its function.

A less oxygen is transported
B less nutrients are transported
C more carbon dioxide is transported
D more metabolic waste is transported

Explanation:

A the change in one amino acid residue changes the primary structure
B the change in one amino acid residue changes the secondary structure
C the change in one amino acid residue changes the tertiary structure
D the change in one amino acid residue changes the cell structure

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Chapter 3
Effects of Virtual-Reality Elements on Spatial Visualization Skills of Secondary Three Students in Singapore

Hwee Ngee Gwee

Abstract This chapter is part of a larger study investigating the effects of a new virtual-reality elements program on the learning of geometry. The study used an experimental research design (pretest/posttest, control experimental group), to examine the effects of this new program developed by ZEPTH Pte Ltd. The focus of the study is on the spatial visualization skills, achievement in geometry, and attitude and behavior toward geometry of 249 (150 male and 99 female) Secondary three students from seven schools in Singapore. Only the results of the spatial visualization skills are reported here. Students in the control group ($N = 114$) were taught the topic of three dimensional geometry using the "Chalk and Talk" method, while students in the experimental group ($N = 135$) used the virtual-reality elements program to explore the properties within the three dimensional figures on the same topic. The study has confirmed that the use of the virtual-reality elements program yielded positive results for spatial visualization skills. This can be attributed to the visual representations that the virtual-reality elements program generates for students to explore and understand the topic of three dimensional geometry, allowing the students to see the three dimensional figures on the screen instead of 'imagining' on the whiteboard or on paper.

Keywords 3D • Virtual-reality • Spatial visualization • Mathematics learning

3.1 Introduction

Mathematics is viewed as one of the most important fundamental subjects in the education curriculum of Singapore. The framework (Fig. 3.1) by the Ministry of Education (MOE), Singapore for mathematical teaching and learning is centered

H. N. Gwee (✉)
Hwa Chong Institution, Singapore, Singapore
e-mail: gweehn@hci.edu.sg

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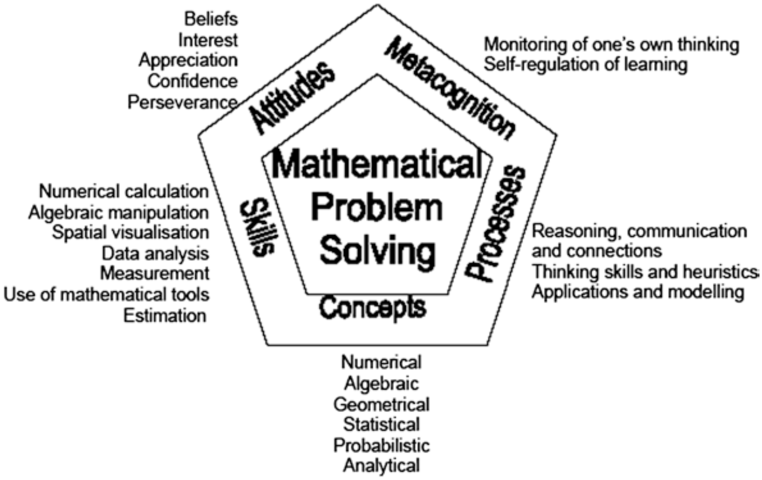

Fig. 3.1 Mathematics framework and pedagogy [7]

on mathematical problem solving at all levels from primary up to pre-university studies [6, 16, 24, 25]. It involves the acquisition and application of mathematical concepts and skills in various situations such as nonroutine, open-ended, and real-world problems. The five strands on developing mathematical problem solving are concepts, skills, processes, attitudes, and metacognition.

Since the launch of the first IT masterplan for education (MPL) by the MOE, Singapore in April 1997, information technology has been widely used in the mathematics classroom [16] and new skills such as spatial visualization and data analysis were introduced into the skills component of the mathematics framework. Emphasis was also placed on the use of information technology to enable students to explore more real-world problems.

This IT MPL has now progressed to the third phase, and a FutureSchools@ Singapore project has been rolled out as an initiative by the MOE. The project aims to harness Infocomm Technology (ICT) effectively for engaged learning and to keep Singapore's education system and programs relevant in preparing students for the future. The FutureSchools comprise a group of schools that is pushing for innovative transformation of the education experience in Singapore, and leading the way for other schools in providing possible models for the integration of ICT into the curriculum. Five schools were selected, and each of them has drawn up its own program according to the needs of their students. These schools are characterized by the implementation of innovative education programs that will leverage on ICT across all levels and subjects. Being one of the chosen schools under this FutureSchools project, Hwa Chong Institution (HCI) has adopted active independent learning and collaborative global learning as its two main thrusts for creating the envisioned passion-driven and borderless learning institution. The school has since collaborated actively with different technological partners on the use of ICT to enhance learning. One of them is with the researchers at Zepth Pte Ltd. This collaboration has led to the building of a virtual-reality laboratory in HCI as well as the development of a new computer program—virtual-reality elements that will allow the learners being able to visualize, create, and manipulate any 3D object projected onto a 3D screen while using an input pen.

3.1.1 Rationale

Spatial visualization, the ability to manipulate an object in an imaginary 3D space and create a representation of the object from a new viewpoint Smith and Strong [26], is a key skill in the learning of geometry. According to Hedberg and Alexander [13], and Winn and Jackson [28], virtual-reality environments can provide 3D explorations. Kwon et al. [14] have suggested that virtual-reality learning environments (VRLE) are able to facilitate the teaching and learning of geometry. Because of their three main features: (1) immersion; (2) interaction; and (3) engaging, these VRLEs have been proposed to help students learn content under some circumstances [4, 8, 9, 23].

The first feature immersion allows students to experience what they are learning in an entirely new way. Objects and actions, whether or not can naturally occur in the real world, can now be represented in directly visible forms, concepts, and procedures [27]. According to Bricken [3], this immersion helps to remove the subject–object distinction between students and what they need to learn, allowing for students to cross that subject–object boundary easier. Also, immersion allows students to interact with the objects and can actively experience phenomena in the virtual world more naturally.

The second feature interaction allows students being able to "touch, see and do" which is considered the best way for learning to occur, according to educational technologists. Psotka [20] indicates that these interactions with objects in a virtual-reality environment make learning much easier and more useful than other environment.

The third feature engaging gives students the experience and the empowerment to control the computer, and get it to do what they want. It is also believed by Winn and Jackson [27] that virtual-reality is able to help students understand concepts and principles that are used to be opaque and baffling, and serves as an intrinsic motivator to the students.

3.1.2 Purpose

The purpose of this study is to investigate the effect of the virtual-reality elements program, developed by Zepth Pte Ltd, on the spatial visualization skills in Secondary three students in Singapore.

3.2 Research Design

A pretest/posttest, control/experimental group design has been used for the linear unidimensional measure on spatial visualization skills. According to Polit and Hungler [19], the three essential elements of such an experimental design are manipulation, control, and randomization. The three elements in this study are as follows:

(1) *Manipulation or Treatment.* Students in the experimental group were taught using the virtual-reality elements method. This method is based on a constructivist approach, using examples related to the topic, students get to discuss the examples and participate in the use of the virtual-reality elements program. Examples are given first, followed by students experimenting before coming up with their own generalizations, rules, and definitions from what they have learnt.
(2) *Control.* The two levels of this element are

(a) *Control Group*. Students in the control group were taught using "Chalk and Talk" method. This method is based on a textbook approach, using chapters of a textbook and examples related to the topic. It is teacher centered and involves lecturing and sometimes questioning. Generalizations, rules, and definitions are given first as a top-down approach, and then examples are provided. The students listen and take notes in their own places [10].
(b) *Constant variables*. For Students: Secondary III, Mathematics Grade. For Experiment: Instructor, Lesson Content, Class Times, Administration of Pretests, and Posttests.

(3) *Randomization.* Students were randomly assigned to either control or experimental groups.

Students were randomly assigned to either the experimental or control group, so as to ensure that the two groups possessed similar characteristics from the start of the experimental design, especially in regard to the variables that might make them learn better in one group compared to the other. To find out the effectiveness of this treatment to the experimental group, the dependent variables were measured twice, before and after the manipulation of the independent variable.

3.3 Sample

This study involved 249 (150 male and 99 female) students from seven Singapore schools offering the Singapore mathematics curriculum. All these students were 15 years old, at Secondary III level and were randomly assigned to the experimental group ($N = 135$) and control group ($N = 114$). In all these schools, students had attained an A or A* grade in mathematics for the primary school leaving

Table 3.1 Primary school leaving examinations T-score of the seven schools

Years	School A	School B	School C	School D	School E	School F	School G
2008	203	227	207	247	243	261	265
2009	206	228	210	249	244	259	263
2010	207	226	211	247	241	257	263

examinations (PSLE). PSLE is a national examination in the Singapore education system, with a possible T-score of 300, which is taken by all students at Primary 6.

Using these PSLE results of the students, a purposive sampling of the seven schools was done—two were among the top ranking schools, two were among the middle ranking schools, and three were among the bottom ranking schools. This ranking system is an interesting phenomenon in the Singapore education system, where all secondary schools in Singapore are ranked according to the lowest PSLE T-scores that they have accepted. This inherently becomes a measure to determine the quality of students for the school, that is, the lower the T-score, the lower the ranking for the school. Table 3.1 shows the quality of intake of these seven schools based on the PSLE T-score over the past 3 years based on information released by MOE. The T-scores reported are relatively stable and give a good indicator of the quality of the students.

3.4 Treatment: Virtual-Reality Elements

The virtual-reality elements program is designed to be a blend between mathematics classroom teaching as well as mathematics laboratories. Situated in one of the rooms in HCI's Science Research Centre, the virtual-reality laboratory is constructed with high-end graphics and display hardware, and high performance computers. This virtual-reality laboratory has an in-built virtual-reality elements program which supports real time, and realistic visualization and modeling. The design of this virtual-reality laboratory takes into account various factors in classroom teaching for a class of about 30 students. A front projection system is adopted due to the room dimensions and the provision of a free seating space within a suitable field of view. High-quality immersive effects are generated from the integration of the high-quality images projected on an anti-reflective screen. The hardware of the virtual-reality laboratory consists of a stereographic display subsystem and an interactive subsystem. The interactive subsystem has (1) a control pad to input commands and numbers; and (2) an input pen to create, edit, and manipulate 3D objects.

Virtual-reality elements have five key features, (1) 3D native; (2) primitive based; (3) dynamic; (4) visual based; and (5) interactive. The program system works neatly to create a solution for the correct representation of 3D objects. Figure 3.2 shows a 3D user interface, with a 3D Blackboard of three axes, for objects to be displayed and manipulated as well as a 3D Icon Menu feature for files to be opened or

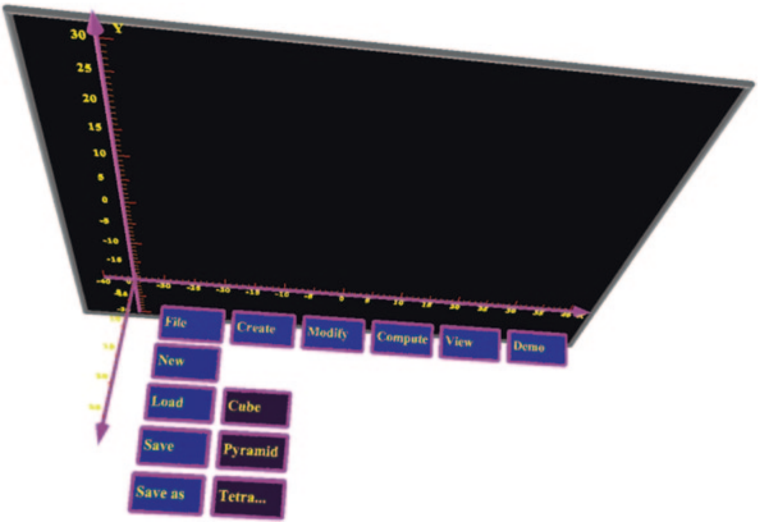

Fig. 3.2 3D user interface of virtual-reality elements program

Table 3.2 Properties of geometrical elements

Elements	Properties
Point	Point ID, position (x,y,z), point color, etc.
Line (segment)	Line ID, two end points, line equation, line segment length, line color, etc.
Plane (area)	Plane ID, plane origin and normal, plane equation, plane boundary segments, Planar area, plane color, etc.
Cube	Cube ID, cube center, cube size (width, height and depth), cube volume, cube boundary faces, cube surface area, cube color, etc.
Sphere	Sphere ID, sphere center, sphere radius, sphere equation, sphere volume, sphere surface area, sphere color, etc.
Other primitives	Primitive ID, primitive parameters, primitive volume, primitive surface area, primitive color, etc.

saved. The interactive subsystem has 6 degree of freedom (6DOF) tracking and 3D digitizing functions. It allows interaction in various modes, for example, insertion, selection, and transformation. In insertion mode, basic geometrical objects can be created. In selection mode, each geometrical object can be selected for modification. If the selection contains two objects, their relationship, if any, can be derived. In transformation mode, objects can be rotated, translated, or scaled.

The virtual-reality elements program comprises the core layer and the application layer. The basic geometrical elements of the virtual-reality elements program are points, lines, planes, cubes, spheres, etc., as shown in Table 3.2. Virtual-reality elements are mainly designed for learning fundamental geometry topics in 3D space.

The relationship between two elements can be obtained with the virtual-reality elements program as shown in Table 3.3.

Table 3.3 Relationship between two elements in the virtual-reality elements program

Relation	Properties
Visual relation	Hidden/visible, wireframe/color/texture/rendered, open or closed, static or dynamic, etc.
Spatial relation	Colinear or coplanar, inside or outside, perpendicular/parallel/intersect/skew, distance/shortest distance, etc.

3.4.1 Distance and Angle

The virtual-reality elements program can be used to learn various types of distance concept. These distances include point–point distance, point–line distance, point–plane distance, line–line distance, plane–plane distance, and line–plane distance.

In 3D space, two lines may or may not intersect. A line can either intersect with or be parallel to a plane; two planes always intersect. The angle formed by two intersecting elements can be interactive displayed using the input pen.

The virtual-reality elements program allows users to dynamically illustrate the distance or angle concepts. For example, a line segment can be rotated in 3D space, during which, its associated distance or angle will be dynamically updated. In Fig. 3.3, the shortest distance between two lines can be dynamically displayed.

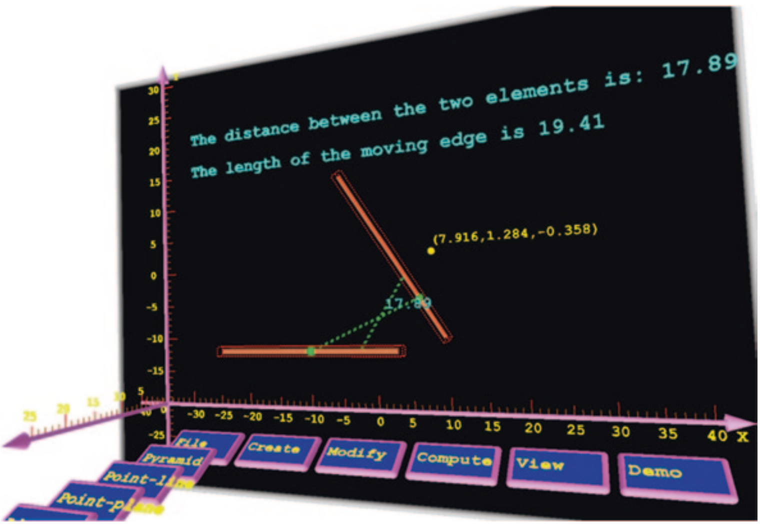

Fig. 3.3 Dynamic demonstration of shortest distance between *two lines*

3.5 Purdue Spatial Visualization Test

The Purdue Spatial Visualization Test—Rotations consist of 20 items of increasing level of difficulty. It is a 10 min timed test appropriate for individuals aged 13 and older [12]. Some of the items require 90° rotation, or 180° rotation of about one axis, while others require a combination of rotations, either both 90° rotations about two axes or 90° rotation about one axis and 180° about another. Students taking this test were given instructions to: (1) study how the object in the top line of the question is rotated; (2) picture in their mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner; and (3) select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question, the one that looks like the object rotated in the correct position. This is shown in Fig. 3.4.

In this study, permission was granted from the inventor via electronic mail for the use of the Purdue Spatial Visualization Test—Rotations. Due to copyright issues, no sample will be provided here. Modifications to the Purdue Spatial Visualization Test—Rotations have been made in order to ensure relevance to the Singaporean context. Two versions of this Purdue Spatial Visualization Test were created as pretest and posttest. In order to ensure that each of these tests has items of comparable levels of difficulty, the pretest was arranged to consist of the odd-numbered items and posttest to consist of the even-numbered items from the original 20-item Purdue Spatial Visualization Test. Also, for measurement purposes using the RUMM2030 program, an ordered marking response scheme has been created for each item. Scores were given from 0 to 4 for each choice such as

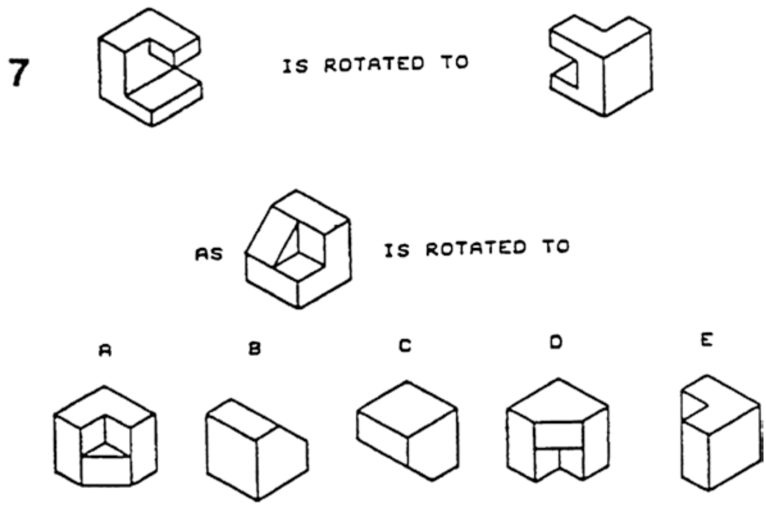

Fig. 3.4 Item 7 from the 20-item version of the purdue spatial visualization test—rotations. (copyright, purdue research foundation, used with permission from professor Guay)

Table 3.4 Scoring rubric for pretest of purdue spatial visualization test—rotations

Question/score	A	B	C	D	E
1	4	3	2	0	1
2	4	0	2	3	1
3	0	1	2	3	4
4	1	4	2	0	3
5	4	0	1	2	3
6	3	4	0	2	1
7	4	0	1	2	3
8	0	3	2	4	1
9	0	4	2	1	3
10	2	3	0	4	1

Table 3.5 Scoring rubric for posttest of purdue spatial visualization test—rotations

Question/Score	A	B	C	D	E
1	2	1	3	4	0
2	0	4	1	2	3
3	1	3	4	0	2
4	0	1	3	2	4
5	2	1	4	0	3
6	2	1	0	3	4
7	1	2	0	3	4
8	4	2	3	0	1
9	1	2	3	4	0
10	2	3	0	1	4

A (score 0), C (score 1) B (score 2), D (score 3), E (score 4) depending on which alternative is more correct. The scoring rubric for the pretest and posttest is shown in Tables 3.4 and 3.5.

With these items ordered by difficulty and a clear ordered marking scheme, it is possible to test both of them using Rasch analysis. Based on the conception of the item difficulty of the variable, items are designed in line with the predicted difficulty, and then data are collected and compared on the same scale with the predicted item difficulties.

3.5.1 Comparison of Posttest Results

The students in the experimental group ($M = 2.42$, SD = 0.89, $N = 135$) were not significantly better than those in the control group ($M = 2.60$, SD = 1.07, $N = 114$) with regard to the spatial visualization skills, $F(1, 247) = 2.20$, $p = 0.14$, as measured for spatial visualization at the end of the experiment (Table 3.6).

Table 3.6 Posttest results for purdue spatial visualization test—rotations between experimental group and control group

	Sum of squares	*df*	Mean square	*F*	Significance
Between groups	2.08	1	2.08	2.20	0.14
Within groups	234.13	247	0.95		
Total	236.21	248			

3.5.2 Comparison of Pretest Results

The students in the experimental group ($M = 2.13$, SD = 1.01, $N = 135$) were not significantly better than those in the control group ($M = 2.20$, SD = 0.97, $N = 114$) with regard to the spatial visualization skills, $F(1, 247) = 0.32$, $p = 0.57$, as measured for spatial visualization at the beginning of the experiment (Table 3.7).

Table 3.7 Pretest results for purdue spatial visualization test—rotations between experimental group and control group

	Sum of squares	*df*	Mean square	*F*	Significance
Between groups	0.32	1	0.32	0.32	0.57
Within groups	244.12	247	0.99		
Total	244.44	248			

3.5.3 Posttest Versus Pretest Results for Experimental Group

The students in the experimental group did significantly better in the posttest than the pretest in regard to the spatial visualization measure, $F(1{,}268) = 6.25$, $p = 0.012$ (see Table 3.8). This means that the spatial visualization skills of the students taught using the virtual-reality elements method was almost significantly better at the end of the experiment compared to the beginning.

Table 3.8 Statistics for purdue spatial visualization test—rotations by pretest and posttest for experimental group

Experimental	Pretest	Posttest
Mean	2.13	2.42
Standard error	0.09	0.08
Standard deviation	1.01	0.89
Confidence level (95.0 %)	0.17	0.15
Number of students	135	135

3.5.4 Posttest Versus Pretest Results for Control Group

The students in the control group did significantly better in the posttest than the pretest in regard to the spatial visualization measure, $F(1, 226) = 8.83$, $p < 0.01$

Table 3.9 Statistics for purdue spatial visualization test—rotations by pretest and posttest for control group

Control	Pretest	Posttest
Mean	2.20	2.60
Standard error	0.09	0.10
Standard deviation	0.97	1.07
Confidence level (95.0 %)	0.18	0.20
Number of students	114	114

(see Table 3.9). This means that the spatial visualization skills of the students taught using the "Chalk and Talk" method were significantly better at the end of the experiment compared to the beginning.

3.6 Conclusion

Spatial visualization was measured with the well-known Purdue Spatial Visualization Test—Rotations, but the person separation index was very low at 0.29. The items were initially developed in the United States of America under a True Score Theory measurement paradigm and this can be a problem with Rasch measurement. The main problem appears to be the poor targeting of the items against the range of student measures, because there are insufficient items at the high end of the scale to target the students with better spatial visualization skills. The items were not conceptually developed from easy to hard. The targeting graphs showed that the person measures cover a range of about –0.2 to +3.8 logits and the item difficulties cover a range of about –2.4 to +2.2 logits. This means that the targeting of the items needs to be improved by including harder items to better target students with better spatial visualization skills. Hence, any inferences made with the measures for this variable need to be treated with some caution.

Nevertheless, the results from the repeated measures analysis of variance (ANOVA) tests, in two instances (1) using separate pretest and posttest linear Rasch measures, and (2) using the pretest linear Rasch measures on the same scale as the posttest linear Rasch measures, showed that there is no statistically significant interaction effect, $F(1, 247) = 1.401$, $p = 0.238$ and $F(1, 247) = 3.268$, $p = 0.140$, respectively, but there is a statistically significant main effect, $F(1, 247) = 1881$, $p < 0.001$ and $F(1, 247) = 2027$, $p < 0.001$, respectively. This means that both the control group, taught using the "Chalk and Talk" method and the experimental group, taught using the virtual-reality elements method improved in spatial visualization about the same amount over the course of the experiment. These results agree with the numerous other studies suggesting that spatial visualization skills can be improved through training [1, 2, 11, 17, 18, 22] as well as with the use of technology [5, 14, 15, 18, 21].

Findings from the study have confirmed that the use of the virtual-reality elements program, developed by Zepth Pte Ltd, yielded positive results for spatial visualization skills. This positive effect can be attributed to the visual representations that the virtual-reality elements program generates. The use of this program has provided a visual way for students to explore and understand the topic of 3D geometry, allowing the students to see the 3D figures on the screen instead of 'imagining' on the blackboard or on paper. These results also support the constructivist learning theories for a virtual environment [9]. Students are able to immerse themselves in the synthetic environments, and are able to learn by doing, using the virtual artifacts to construct knowledge. These interactions between students and the virtual technology are able to enhance the students' interpretation of a typical interaction with the external world, and have "magically" shaped the fundamental nature of how learners experience physical and social contexts.

Acknowledgments The author would like to thank National Research Foundation for supporting the FutureSchools@HCI project. Thanks should also go to Professor Yiyu Cai and Dr Winston Chen for their collaboration in this research.

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Chapter 4
The Virtual-Reality Campuses Project

Ban Hoe Chow

Abstract Virtual-reality Campuses was a project designed for River Valley High School (RVHS) students to (1) learn the latest virtual-reality (VR) technology, (2) apply VR technology to create VR campuses of the school in its history, and (3) use the VR Campuses for the purposes of school heritage education, as well as safety and security education. Through this project, students were exposed to innovative research and development in the emerging field of interactive and digital media (IDM). With the aid of VR Campuses, RVHS students can now enhance their bonding with the School through a better understanding of the school history. RVHS also uses the VR Campuses in the education of campus security and laboratory safety. The VR Campuses project was shortlisted to represent Singapore in the Asia Pacific ICT Alliance (APICTA) Award Competition held in Melbourne, Australia in 2009.

Keywords Virtual-reality • 3D campuses • Modeling • Visualization • School heritage • Safety and security education

4.1 Introduction

Founded in 1956 and occupying the premises of Seng Poh Primary School, River Valley High School (RVHS) was known initially as the Singapore Government Chinese Middle School (Fig. 4.5). It was set up by the government as the first Chinese secondary school in Singapore. It was renamed Queenstown Government Chinese Middle School in 1957 when it was moved to Strathmore Avenue. In 1958, it was further renamed River Valley Government Chinese Middle School after it was relocated to Jalan Kuala. The school admitted its first batch of English stream pupils when it was selected as one of the nine special assistance plan (SAP) schools in 1979. From 1986 to 2004, the school was housed at West Coast Road using the name River Valley High School. It was among the first six schools in

B. H. Chow (✉)
River Valley High School, Singapore, Singapore
e-mail: chow_ban_hoe@moe.edu.sg

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Singapore to be accorded the autonomous school status in 1994. From 2005 to the middle of 2006, the school had its operation at Commonwealth Avenue. In September 2006, RVHS was given the approval to offer the 6-year Integrated Program. In late 2006, the school was shifted to Malan Road and it now has its final permanent location in Boon Lay Avenue since December 2009.

Over 55 years, RVHS changed seven campuses which is rather unique to a school's history. Originally, the RVHS Virtual-reality (VR) Campuses started as a major project in 2008 to capture images of the various school campuses. Over the past 3 years, several students from RVHS have contributed to this project, which has evolved into a continuous effort with newer applications extending from documentation of the school to safety and security education.

In the following sections, we will first introduce the VR technology which is the fundamental tool used in this project. We then present the design of the Virtual Campuses project, and the two phases of the project development. This will be followed by a conclusion and a discussion on the future developments.

4.2 Fundamentals of VR Technology

4.2.1 VR History

VR has a fairly long history. In 1965, Ivan Sutherland described the key concepts of simulated immersion and sensation through "the ultimate display" [1]. According to him, the challenge is to "make that world look real, act real, sound real, and feel real". To achieve this vision, Sutherland [2] invented the world's first head-mounted display which was designed to immerse the viewer in a visually simulated 3D virtual environment. Over the past four decades, the VR technology has made astonishing progress and has been used in many fields such as entertainment, engineering, medicine, and training, etc [3–6].

4.2.2 VR Modeling, VR Visualization, VR Interaction, and VR Interface

The VR technology typically consists of four major components (Fig. 4.1). Modeling plays a central role in VR with an emphasis on 3D fidelity. Stereographic visualization is often used to achieve visual immersion. Real-time interaction can also significantly improve the realism of the simulated virtual environment. The natural user interface of gesture-based input is increasingly being used in VR. All these four components work together to make the virtual world look real, act real, sound real, and feel real. This project aims to develop 3D virtual-reality campuses with functions of immersive stereographic visualization and real-time interaction.

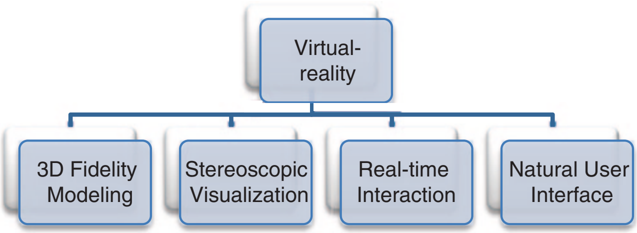


Fig. 4.1 VR modeling, visualization, interaction, and interface

4.2.3 Virtual Walk Through and Virtual Fly Over

Virtual walk-through and virtual fly-over are two of the most commonly used techniques in VR. For instance, the virtual walk-through technique is widely used in virtual museums or galleries, while virtual fly-over is a common approach to terrain visualization with a bird's-eye view from the sky. The two techniques are ideal for immersive and interactive visualization of virtual-reality campuses, such as walking through indoor classrooms, libraries, and offices, as well as flying over outdoor settings such as the school sports field and gardens, etc.

4.3 The Design of VR Campuses Project

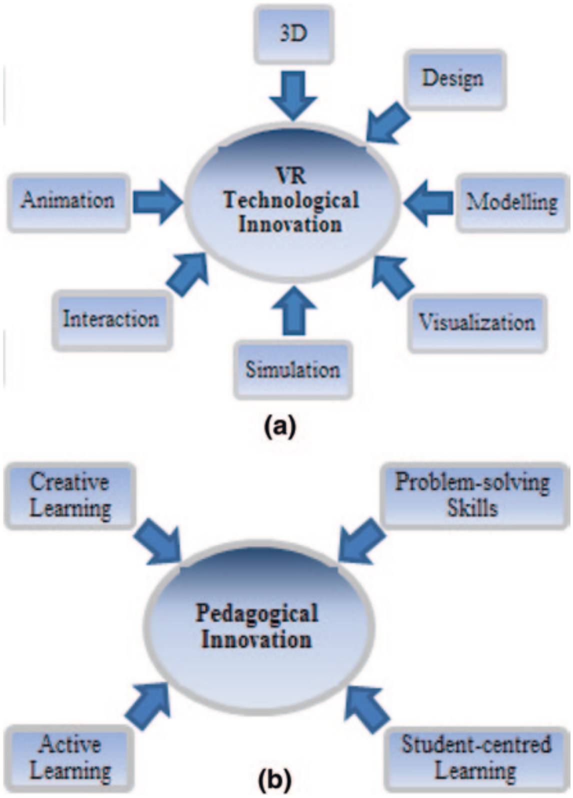
4.3.1 The Project Objectives

VR Campuses is a project designed for RVHS students to learn the latest VR technology. The focus of the project is for students to apply VR technology to construct virtual-reality campuses in the long history of the school. The project can be used for various educational purposes from the documentation of school heritage to the education of campus security and laboratory safety. Through this project, students are exposed to the innovative research and development in the booming fields of VR, as well as interactive and digital media (IDM). With the aid of virtual-reality campuses, RVHS can promote stronger school bonding amongst students through a better understanding of their school history, as well as heighten their awareness of school security and safety through simulations in a virtual school compound.

4.3.2 The Project Design

The design of the RVHS Virtual Campuses emphasizes the learning of VR technological innovation. In particular, students will learn various VR techniques, including 3D modeling, visualization, and simulation (Fig. 4.2a). At the same time, the

Fig. 4.2 Technological and pedagogical innovations



design takes into account the pedagogical approaches (Fig. 4.2b), wherein students play an active role in the project in tasks from literature reviews to brainstorming and conceptual design, as well as from project planning to development. They work in teams typically of two to three people. This project helps students improve their critical thinking, problem solving skills, and gain practical knowledge and experience of VR applications.

4.3.3 Project Planning, Implementation, and Assessment

Interested students were recommended by their teachers to apply for the participation in this project. Typically, these students has a strong interest in ICT but have little prior knowledge of 3D or VR. Shortlisted students would go for a selection interview before they are accepted for the project. After a pre-project briefing, the students will start team building and then embark on planning and scheduling. They will then do an intensive brainstorming for preliminary project ideas. Special training will be arranged for them to learn the essential programming and graphic designing skills for VR. The basic skills or techniques they learnt include

#	Stage	Task
1.	Project initial stage	Briefing
		Team-building
		Planning
		Scheduling
		Brainstorming
		Training
2.	Project implementa-tion stage	Regular technical discussion
		Regular follow-up meetings
		Regular consultation with mentor
		Testing and fine-tuning of animation
3.	Project assessment stage	Interim progress report
		Final report submission
		Oral and poster presentation
		Demonstration
4.	Post-project stage	Public exhibition or showcase
		National or international competition
		Publication of research findings
		Sharing of research findings at conference and symposium

Fig. 4.3 Key stages in the project work

3D modeling, animation, and visualization. This initial stage would take about a month from late May or early June.

The project implementation stage would take place over 6 months. During this period, students will have regular team meetings to discuss technical issues and to update work progress. Testing and fine-tuning of the product were involved in the later part of the stage. Students would also have regular consultation sessions with their mentors.

Groups of students worked on these research projects under the mentorship of Associate Professor Yiyu Cai, from Nanyang Technological University, as part of the Nanyang Research Program (NRP). At the end of the year, students would submit their final project report to summarize their research findings and experience. They would also do a team oral or poster presentation to showcase their projects where the demonstration of their final product is one of the key performance indicators. Figure 4.3 outlines the stages in the project work.

4.4 Project Phase 1: Development of RVHS VR Campuses

RVHS Virtual-reality Campuses is an ongoing project initiated in 2008. This section reports on the key developments in Phase 1 (2008–2009) with two students working on this team project.

4.4.1 3D Modeling and Animation of the RVHS VR Campuses

When the project commenced in 2008, RVHS was still occupying a holding school at Malan Road, while the new school compound was undergoing construction at a permanent site in Boon Lay Avenue. Based on the blueprints and artistic impressions, the students created a virtual campus of the new school premises. The 3D models of the school layout and buildings provided a virtual visualization of the future RVHS campus to be ready by the end of 2009. The models also offered the built-up settings for the VR walk-through and fly-over approaches in maneuvring within this virtual campus (Fig. 4.4).

4.4.2 3D Photography of the Virtual-Reality Campuses

Among the previous campuses in RVHS history, only those at West Coast Road, Commonwealth Avenue, and Malan Road still exist. Some of these present school premises are occupied by other schools or organizations of the Ministry of Education, Singapore. 3D photography is used to capture static pictures of the remaining school buildings or structures at these historical sites. Figure 4.5 shows some selected sites or buildings of these old RVHS campuses. The 3D anaglyph photos and models are archived as a multimedia data resource in a 3D system, and are incorporated to show the complete overview of the former campuses of RVHS.

4.4.3 Exhibitions and Presentations of VR Campuses

The virtual-reality campuses developed in this phase were exhibited in several events, such as the Public Service 21 ExCEL Convention in 2008 (Fig. 4.6). The

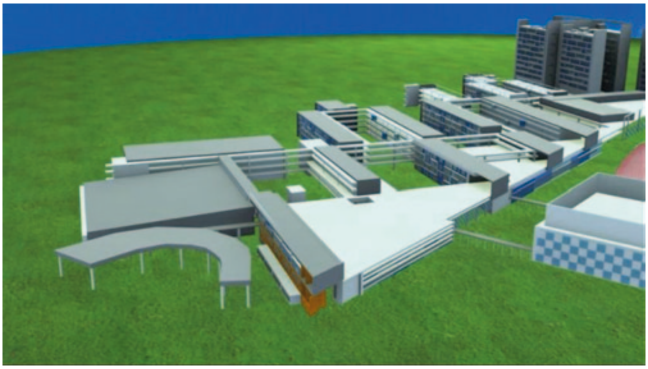
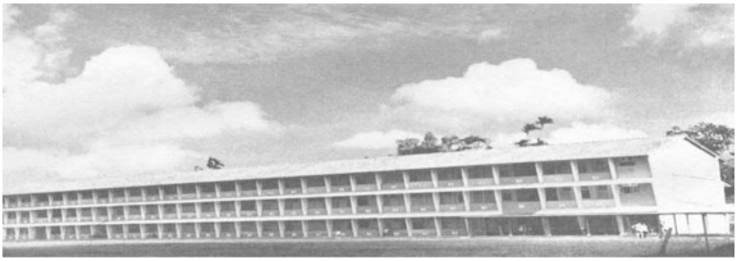


Fig. 4.4 3D modeling of the RVHS permanent campus in Boon Lay Avenue



(a)

(b)

Classrooms School Canteen Science Garden & Eco-pond

(c)

Backyard Near Basketball Courts Classrooms Tennis Courts

(d)

Grandstand Near School Field Canteen Container Block of Class-rooms

(e)

◄**Fig. 4.5** 3D photos of the former RVHS campuses. **a** Strathmore Avenue Campus—Queenstown Government Chinese Middle School (1957). **b** Jalan Kuala Campus—River Valley Government Chinese Middle School (1958–1985). **c** West Coast Campus—River Valley High School (1986–2004). **d** Commonwealth Avenue Campus—River Valley High School (2005–2006). **e** Malan Road Campus—River Valley High School (2006–2009)

Fig. 4.6 Exhibitions and presentations of virtual-reality campuses. **a** Public showcase at Nanyang Research Program Symposium. **b** Exhibition at the Public Service 21 Convention. **c** Singapore Information Technology Federation (SiTF) awards ceremony in 2009. **d** Participation at Asia-Pacific Infocomm Technology Awards Competition 2009

RVHS VR Campuses project was also showcased at the International Simulation and Gaming Association Conference in 2009. The students' work also garnered a Gold Award in the annual Nanyang Research Program Symposium in 2009 and 2010. In 2009, the RVHS VR Campuses project won a Merit Award at the Singapore Infocomm Technology Federation (SiTF) Awards Competition. The SiTF Award is a local industrial award which recognizes the most innovative infocomm technology solutions developed by companies and schools in Singapore. With this success, the team proceeded to the international arena, as one of the two schools to represent Singapore to vie for the prestigious and keenly contested Asia-Pacific Infocomm Technology Awards (APICTA) Competition held in Melbourne, Australia in the same year.

4.5 Project Phase 2: Educational Applications of VR Campuses

After successful completion of Phase 1 in 2008, the RVHS VR Campuses progressed on to Phase 2 in 2009. During the Public Service 21 Convention, RVHS was invited by the Ministry of Home Affair (MHA), Singapore to develop an extension to the project with a new application for promoting security and safety education. This section will report on the Phase 2 development from 2009 to 2010 with three students working on the project.

4.5.1 Campus Safety and Security Education

Security awareness is of paramount importance, as schools occasionally do face problems such as theft, vandalism, outbreak of fire, and breach of IT security. In addition, there are new challenges such as the threat of terrorism and cyber crimes.

The focus of Phase 2 was to expand the use of RVHS Virtual-reality Campuses in creating a 3D virtual tour video of the school premises to showcase possible good security and safety measures which could be put in place to ensure the well-being of all its occupants. This product can be used to build a culture of security awareness among our stakeholders, namely the students, parents, alumni, vendors, and school volunteers. For instance, the video highlighted the conventional as well as possible safety features in a typical school setting, such as fire extinguishers in the science laboratory and fire-resistant shutters in the school canteen. Figure 4.7 shows static scenes of safety features within the virtual campus. For security education, the students introduced the use of futuristic security innovations, such as the latest biometric fingerprint recognition technology in gantries at the school gate to ensure restricted access to the school compound.

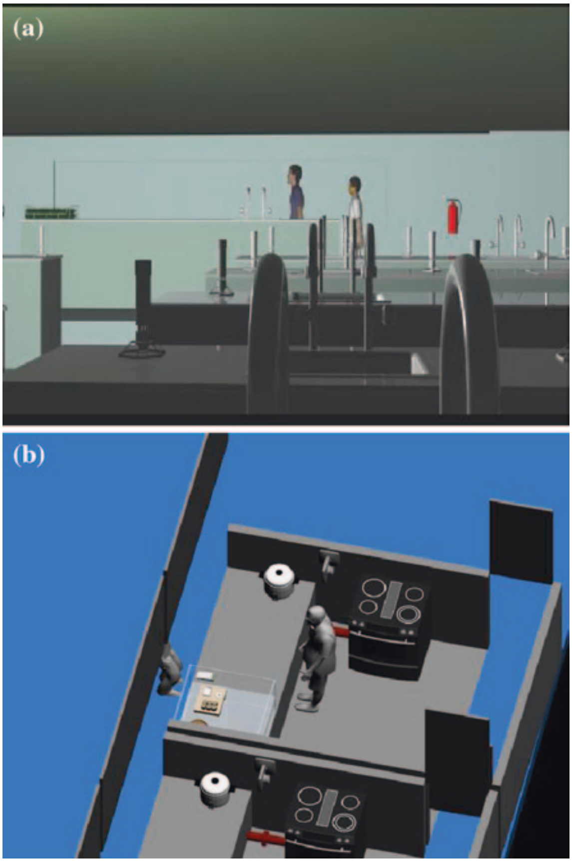


Fig. 4.7 Lab and campus safety and security: **a** safety features in the science laboratory, and **b** safety features in the school canteen kitchen

4.5.2 Project Showcase at MHA Home Team Innovation Fest 2009 and Home Team Convention 2010

The Phase 2 project took part in the MHA Security Awareness for Everyone (SAFE) Program in 2009. The 3D video entry was awarded the Gold Award (Secondary School Category) at the MHA Home Team Innovation Fest (Fig. 4.8). The following year, the project was showcased at the MHA Home Team Convention.

4.6 Conclusion

This chapter presents the project of RVHS Virtual-reality Campuses which capture the development of the school building over the decades. The details of the planning and implementation stages of the project are discussed. Through this project, students learn the latest VR technology and gain practical knowledge as well

Fig. 4.8 Project showcase at MHA Events. **a** MHA Home Team Innovation Fest in 2009. **b** MHA Home Team Convention in 2010

as experience on 3D modeling and visualization. RVHS Virtual-reality Campuses have been put in use for school heritage, security, and safety education.

There are several areas for further work in this project. Firstly, the campuses of RVHS can be better integrated in the various forms of media. Secondly, more details of the RVHS history and heritage can be added to the virtual-reality campuses. To improve interactivity with the virtual-reality campuses, 3D avatars can be designed and introduced into the media making the virtual worlds closer to reality. Educational games can also be strategically developed and included within Virtual-Reality campuses allowing students to learn through engaging and immersive gaming. In addition, a Virtual Hall of Fame can be virtually constructed to feature the RVHS principals and top scholars in the past school history. As proposed, walk-through and fly-over techniques can be incorporated to further enhance the immersive and interactive experience within the surreal world of RVHS Virtual-reality Campuses.

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Chapter 5
Cultivating STEM Education Through 3D Sabbaticals

Joseph Tan, Boon Keong Ngo, Indhumathi Chandrasekaran and Yiyu Cai

Abstract The global competition in the knowledge economy has called for a profound change in education. To have sustainable economic development within any nation, education in Science, Technology, Engineering, and Mathematics (STEM) plays a crucial role. This chapter will present a new initiative on 3D sabbaticals with Hwa Chong Institution (HCI) for students to learn STEM using 3D as a tool. It is a 20 h elective module conducted in the school thrice a year. Each sabbatical lasts 5 days. Technology-rich Outcome-focused Learning Environment Inventory (TROFLEI) is applied to assess the 3D sabbaticals in terms of nurturing students' competencies such as inventive and collaborative learning, 3D ICT literacy, etc. Over the years in the sabbaticals, several topics including Unmanned Aerial Vehicle design and Formula One simulation have been developed for HCI students to learn STEM.

Keywords 3D • Science • Technology • Engineering and Mathematics education • Technology-rich outcome-focused learning environment inventory • Modeling • Simulation • Visualization • Interaction

5.1 Introduction

With increasing globalization, science, technology, and engineering have become arenas in which different nations compete. Sustainable development in any economy heavily relies on education in science, technology, engineering, and mathematics (STEM). The American Competitiveness Initiative released by the US Government in February 2006 was to attract more students to learn STEM [4]. The reports from

J. Tan
Hwa Chong Institution, Singapore, Singapore

B. K. Ngo
ZEPTH Pte Ltd, Singapore, Singapore

I. Chandrasekaran · Y. Cai (✉)
Nanyang Technological University, Singapore, Singapore
e-mail: myycai@ntu.edu.sg

Y. Cai (ed.), *3D Immersive and Interactive Learning*,
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the Program of International Student Assessment (PISA) [2] have also motivated the country to pass the America Competes Act of 2007 and launch the campaign on “Educate to Innovate”, inspiring US students to excel in Science and Math.

Singapore has always emphasized the importance of STEM education. Students are encouraged to do enrichment programs for STEM learning and research. Since 2001, the Ministry of Education (MOE), the Agency of Science, Technology, and Research (A*STAR), and the Singapore Science Centre (SSC) have been jointly organizing the Singapore Science and Engineering Fair annually to promote scientific research and STEM learning. Students from schools in Singapore have various opportunities to participate in different activities related to STEM.

This chapter will share the 3D sabbaticals program designed to promote STEM learning in Hwa Chong Institution (HCI). Section 5.2 will discuss the design of 3D sabbaticals. Section 5.3 will detail two selected sabbaticals organized recently as a case study. Section 5.4 will present an initial assessment study of the program. Section 5.5 will conclude the research.

5.2 The Design of 3D Sabbaticals

The 3D sabbatical was initiated in 2007 under HCI’s Integrated Program. The idea was to design and develop an elective module motivating students (especially at high school level) to learn STEM. The program emphasizes “student centric learning” and team project work.

As an elective module, the 3D sabbatical is open to all secondary students. The class size is typically of 20–30 students. It is interesting to see, in the sabbaticals, students of different ages sitting in the same class to learn something of their common interest.

In the 3D sabbaticals, students learn STEM knowledge, gain 3D skills, and develop their competencies. Each sabbatical will have a theme focusing on a specific topic in STEM. Over the past few years, themes of 3D sabbaticals conducted include Star Warship, Domino Effect, 3D Avatars, Virtual Campus, Formula One, Unmanned Aerial Vehicles, etc. These topics allow students to learn basic knowledge of STEM. Furthermore, students will have a chance to learn basic 3D skills for designing and modeling, as well as animating and rendering. During the sabbaticals, students will be grouped into teams, and each team will work together for their project work. For instance, the Star Warship was the first sabbatical conducted in 2007 (Fig. 5.1). Students attended this sabbatical to learn basic knowledge of Space science and Engineering in addition to Physics such as gravitation in the first and second days. They then picked up basic skills of 3D modeling, animating, and rendering in the third and fourth days. They worked in teams to design their own Star Warships as project work using the 3D skills they learned. Each project team did brainstorming, and inventive thinking to have their innovative ideas implemented in the team projects. Through the projects, students developed collaboration, team spirit, and also friendships.

Fig. 5.1 The Star Warship sabbatical in 2007

5.3 Case Study

In this section, we will discuss two sabbaticals: one on Formula One and another on Unmanned Aerial Vehicle.

5.3.1 3D Sabbatical: Formula One Car Design

Formula One (F1) is one of the popular sabbaticals in high demand by HCI students. This is partially due to the Singapore F1 Night Race since 2008. On days 1–2 of the sabbatical, students will learn basic knowledge of car design, engine, steering system, materials, etc. In the next 2 days, they will learn 3D skills for designing, animating, and rendering. They apply the basic knowledge and skills they learned to design their own F1 cars. Project teams are typically formed with 2–4 members. An interesting phenomenon often seen with the sabbatical is that students of different ages or grades work together on their team project. Creative and innovative thinking, collaborative and independent learning are developed through the hands-on projects. At the end of the sabbatical (day 5), students will do a team presentation to summarize their learning and also showcase their innovations. Figure 5.2 shows five different F1 cars designed by one of the teams in the 2008 3D sabbatical.

5.3.2 3D Sabbatical: Unmanned Aerial Vehicle Design

Unmanned Aerial Vehicle or Unmanned Air-reconnaissance Vehicle (UAV) is an aircraft with no onboard pilots needed during a flight. In this UAV 3D sabbatical,

Fig. 5.2 F1 cars designed in the 2008 3D sabbatical

Fig. 5.3 Unmanned Aerial Vehicle designed by a team with the 2009 3D sabbatical

students will be first introduced to the Luftgestützte Unbemannte Nahaufklärungs Ausstattung (LUNA), a well-known UAV made in Germany. LUNA is designed mainly for real-time surveillance, reconnaissance, and target location at ranges exceeding 80 km. Students will then be asked to investigate the advantages and disadvantages with the current LUNA design for the purpose of having possible improvements in various directions. Next, students will learn necessary 3D skills to enable them for innovative designs. Inventive and critical thinking can be developed through their collaborative project work. Students are encouraged to propose and implement novel ideas in areas such as navigation and launch systems in their design.

Figure 5.3 shows a UAV designed in the 2009 3D sabbatical.

5.4 Assessment

This section will present an initial study of the assessment of the 3D sabbatical using the modified Technology-rich Outcome-focused Learning Environment Inventory (TROFLEI) method [1].

TROFLEI is used to study the influence of the classroom environment in schools on student learning [3]. Different from most of the TROFEI research with a focus on the effects of computer usage, we developed a modified TROFLEI to investigate the influence of 3D technology for the sabbaticals. The original TROFLEI consists of 80 items assigned with 10 underlying scales (8 items per scale). The modified TROFLEI has eight scales each having six items (Table 5.1).

Table 5.2 shows the six items with the environment scale—Students' Cooperation. Students can choose to answer the questions from five grades: Almost Never (1), Seldom (2), Sometimes (3), Often (4), and Almost Always (5).

The two sabbaticals conducted in March and May 2012 were selected for the initial assessment study using a modified TROFLEI. Class 1 of March Sabbatical had 26 participants, and Class 2 of May Sabbatical had 23 participants. Participants were asked to give feedbacks after they completed their sabbaticals. Feedback data were used to analyze the internal reliability and consistency, mean and standard deviation, correlation, analysis of variance (ANOVA), etc. Table 5.3 shows the scale statistics for the total 49 students (Class 1 + Class 2) using the modified TROFLEI method. The Alpha Reliability indicates that students'

Table 5.1 Descriptive information for eight modified TROFLEI scales

Environment Scale	Description
Students' cohesiveness	The extent to which students know, help, and are supportive of one another during the 3D sabbatical
Students' involvement	The extent to which students have attentive interest, participate in discussions, do additional work, and enjoy the 3D sabbatical
Students' investigation	The extent to which skills and processes of inquiry and their use in problem solving and investigation are emphasized during the 3D sabbatical
Students' cooperation	The extent to which students cooperate rather than compete with one another on learning tasks during the 3D sabbatical
Differentiation	The extent to which instructors cater for students differently on the basis of ability, rates of learning, and interests during the 3D sabbatical
Equity	The extent to which students are treated equally by the instructors during the 3D sabbatical
Creativity	The extent to which students have creativity in thinking and designing during the 3D sabbatical
3D usage	The extent to which students use 3D as a tool to do their team project during the 3D sabbatical

Table 5.2 Descriptive information for eight modified TROFLEI scales

Items under environment scale students' cooperation	Grades				
	1	2	3	4	5
I cooperate with other students and do teamwork in this 3D sabbatical					
I enjoy working with my teammates in this 3D sabbatical					
My efforts are recognized by the project team					
I learn from other teammates in this 3D sabbatical					
The team efforts make my project successful					
This 3D sabbatical improves student cooperation					

Table 5.3 Scale statistics for eight modified TROFLEI scales with 49 students from two classes

Class 1 (26 students) and Class 2 (23 students)

Scale	No. of items	Alpha reliability	Mean correlation with other scales	ANOVA (between classes)
Students' cohesiveness (A)	6	0.751	0.460	0.025
Student involvement (B)	6	0.747	0.488	0.046
Student investigation (C)	6	0.904	0.426	0.001
Student cooperation (D)	6	0.851	0.487	0.002
Differentiation (E)	6	0.632	0.490	0.038
Equity (F)	6	0.806	0.435	0.003
Creativity (G)	6	0.815	0.484	0.005
3D usage (H)	6	0.800	0.499	0.013

Table 5.4 Actual and preferred alpha reliability analysis for eight modified TROFLEI scales

Class 2 (23 Students)

Scale	No. of items	Alpha reliability	
		Actual	Preferred
Students' cohesiveness (A)	6	0.817	0.856
Student involvement (B)	6	0.734	0.877
Student investigation (C)	6	0.864	0.836
Student cooperation (D)	6	0.861	0.930
Differentiation (E)	6	0.614	0.868
Equity (F)	6	0.844	0.906
Creativity (G)	6	0.837	0.906
3D usage (H)	6	0.793	0.858

feedbacks on the sabbatical are mostly good (>0.7) or very good (>0.8), except that the differentiation is questionable (0.632). The ANOVA shows the two classes having no significant differences ($p < 0.01$). The sabbatical is excellent in nurturing students' investigations (0.904). The mean correlation also suggests that the eight scales designed are independent.

Table 5.4 shows the scale statistics for Class 2 (23 students) using the modified TROFLEI method. In this case, the students are asked to answer all the questions in two situations: Actual (what students perceived as actually happening in their class) and Preferred (what students would prefer to happen in their class).

5.5 Conclusion

In this chapter, we present the 3D sabbatical, an elective module designed for secondary students to learn STEM and 3D. Each year, three sabbaticals are offered in the high school section with Hwa Chong Institution. In general, sabbaticals are well received since their first inception in 2007. Students from different grades come together spending 20 h in 5 days to learn basic knowledge and skills, and to do team projects. Statistics based on the modified TROFLEI method also reveals that the sabbaticals improve students' performance.

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Chapter 6
A 3D Synergized Discovery and Learning Journey: A Case Study of National Junior College

Nick Choon Loong Chan, Sheryl Siling Ang and Allan Yinglun Goh

Abstract More secondary and high schools in Singapore have taken a keener interest in 3D technology development for educational uses. This chapter focuses on the National Junior College (Singapore) context and discusses how the 3D technology has permeated in its Science Training and Research (STaR) programs and in turn, yielded many learning opportunities for students. The developmental stages, challenges, and successes of its 3D program are detailed. In addition, the design elements of using 3D technology for an International Science Exchange between NJC and a top school in Korea are also presented. The survey results in 2011 show that the 3D program is well received at a rating of 3.7 and 3.1 based on 4-point Likert scale in both the 3D STaR programs and the International Science Exchange, respectively. Short-term and long-term goals of this 3D program have been mapped out and the rigor and motivation of this program will be presented as well.

Keywords 3D • Science training and research • Virtual-reality • International science exchange

6.1 Introduction

6.1.1 Background

3D technology has been identified as a key area in Interactive & Digital Media (IDM) for research and applications. An exciting research example is the assessing

N. C. L. Chan (✉) · S. S. Ang · A. Y. Goh
National Junior College, Singapore, Singapore
e-mail: CHAN_Choon_Loong@moe.gov.sg

S. S. Ang
e-mail: ang_si_ling@moe.edu.sg

A. Y. Goh
e-mail: goh_yinglun_allan@moe.edu.sg

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of nanoleakage patterns qualitatively and quantitatively in 3D, to determine the influence of direction, position, and inclination of the field-of-view [7]. The 3D technology is applied for dentistry research. At the entertainment level, a good number of 3D movies such as Shrek, Toy Story, Transformer, Final Fantasy, Ice Age, etc., have been successfully released. 3D is increasingly used in education. In the United States, a 3D immersive learning environment is created by the Center for Health Promotion and Prevention Research, University of Texas School of Public Health for the middle school curriculum on HIV, STD, and pregnancy prevention [1].

In Singapore, since the 2005 inception of having more ICT-enabled infrastructure and education-infused lessons in higher education [2, 11] and the recent interest and awareness to push for this area by Media Development Authority (MDA) and National Research Foundation (NRF), approximately SGD$1.4 billion (over 5 years) was committed by the Singapore Government [9] to support the research and development in the three areas including IDM [3]. The recently announced Research, Innovation and Enterprise (RIE) 2015 Plan will also provide a $16.1 billion boost to R&D for the next 5 years and the RIE2015 plan will allow peaks of excellence to emerge in the Singapore research landscape. Facilitated by the multiagency Interactive Digital Media R&D Program Office at MDA and funded by the NRF, several IDM R&D institutions have been formed in Singapore. The recent opening of the Institute for Media Innovation (IMI) in Nanyang Technological University was among the entries to the 3D arena. Among various applications, 3D is being actively studied to help autistic children hone their social skills using virtual dolphins, or to predict human behavior during an evacuation using crowd simulation [10].

6.1.2 Rationale

As most high school students are not equipped with basic computing skills, the 3D media technology can become a good platform for them to be enthused due to the visually appealing feature of 3D products. Modeling and dynamic creation of behavior-rich 3D contents can generate excitement for students to “see” the output progress of 3D technology [4]. Computing and programming can become more interesting and thus motivate students to learn the concept and programming language better.

The National Junior College (NJC) has started on its path since 2005 to develop many 3D initiatives in partnership with Dr. Cai from Nanyang Technological University. With a strong motivation and rising trends in this field, NJC’s 3D framework aims to utilize a particular ICT-enabled and focused area in IDM to provide a unique learning experience for students and teachers through its various 3D programs, and possibly to support Teaching and Learning in the near future.

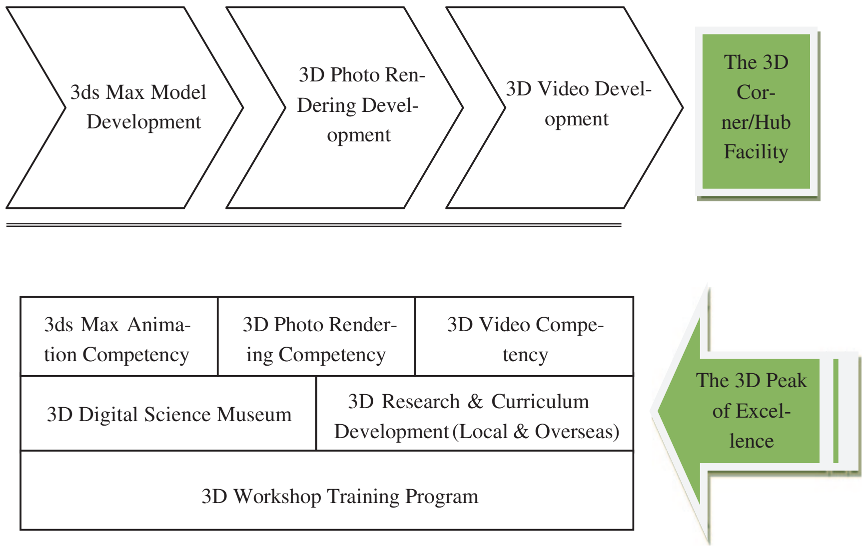

Fig. 6.1 NJC's framework for 3D development and competencies building

6.1.3 Overview

NJC set up a 3D Corner in campus in 2009. The facility with the 3D Corner supports NJC students to design 3D models, create 3D photos, and develop 3D videos (Fig. 6.1). The 3D Corner was upgraded to the 3D Hub in 2011. A 3D digital projection system network is established in the Hub serving as an infrastructure for NJC students to do 3D development. Currently, the 3D Hub is being used by NJC students for their STaR research projects, as well as the International Science Exchange Program.

As seen in Fig. 6.1, the NJC's 3D initiatives include the following:

- 3D workshop in NJC conducted for students as part of a series of 3D animation workshops to provide the necessary 3ds Max programming and 3D photo rendering skills.
- 3D research projects as part of NJC's Science Training and Research Program (STaR), participating in Singapore Science Engineering Fair (SSEF).
- International exchange workshops and projects for one of NJC's International Science Exchange partners
- 3D animation teaching resources for Teaching and Learning resources (2011)

Students attained knowledge and skills in 3ds Max animation, 3D photo rendering, and 3D video. This, in turn, brings about the future sustained development of 3D digital science museums, 3D research and curriculum development (local and overseas), and 3D workshop training programs.

The motivation is to develop 3D capability in NJC in terms of soft skills and hard skills. Soft skills involve the ability to render a 2D photo to become a 3D photo, 3ds Max application, and 3D video making. Hard skills involve putting the 3D facility together and to know how to utilize it and make alteration to it.

The key characteristics of the 3D facility in NJC is that the 3D facility becomes not only a 3D center of excellence for development of 3D products and programs but also a venue for graduated alma mater and 3D research partners to come together for the common goal of enhancing the facility perpetually.

With the seniors or graduated alma mater passing down their skills to the juniors in this facility, the programs become self-sustaining. In the past, the students purchased software and worked on the projects at home only and there was no facility for them to consolidate the resources built. With this facility, space is created for discussion and interaction to improve on the projects. The success of this model lies in the good relationship forged between the school and its students and their willingness to serve.

NJC aims to position itself as the 3D Peaks in Excellence in Singapore by 2015, working closely with universities and other external organizations to tap on the younger creative minds to share on a common platform to produce their creation. With this creation, students can coauthor their work with their researchers, even possibly presenting their work in the international setting.

Being the Center of Excellence (Science & Technology), the South Zone (SZ) South 3 Cluster Science Committee schools are working together to come up with 2D photos to create Singapore's first IDM Digital Science Museum to be put up in the new SZ COE Sigma Lab website. Learning now takes place beyond the curriculum and puts the students in pace with the current drive by MDA and IDM in this area. This capability development is highly scalable and can range from small project teams to across schools in the cluster or even at the national level through conferences or sharing. This facility will become a breeding ground for budding future 3D technopreneurs and researchers.

6.2 The 3D Development and Its Successes

6.2.1 The 3D Development

3D photo rendering is an easy technique and involves learning of optical theory on how our eyes perceive things in 3D via stereoscopic view and different depths of foci. Students can produce their own prints of the 3D photos which they rendered and showcase their work in a gallery. These photos will be archived in the IDM Digital Science Museum, housed in the SZ COE Sigma Lab Website too and viewed online.

3ds Max application allows students to learn some form of computer programming skills. Teachers will facilitate the student projects with the help of the

Fig. 6.2 The jungle and deforestation (Silver Prize SSEF and Gold Award NRP)

graduands or graduates. Various project themes and research topics have been effectively developed using 3ds Max as tools.

3D video making aims to develop educational resources for the teacher to use for lessons although it can be used for many other purposes such as movie making and 3D educational gaming [5]. 3D video making is a highly potential area to work on. Teachers, students, research partners, and external organizations can work together to develop 3D video content for teaching and learning application.

6.2.2 The 3D Projects

Since 2006, numerous students benefited from the 3D training workshops and programs such as local and overseas research programs, competitions, and conferences. Figure 6.2 shows the 3D project—The Jungle and Deforestation which received the Silver Award at Singapore Science and Engineering Fair 2006, and Gold Award in Nanyang Research Program 2006. Figure 6.3 shows three projects developed in 2008 which helped the school to attain The Best Performing School Prize of the National Digital Science & Arts Competition 2008. The project teams were selected to represent Singapore participating in Singapore–Shanghai

Fig. 6.3 From *left* to *right*: Project—solar terrestrial relation observation), project—Singapore night race formula one, and project—unmanned aerial vehicle

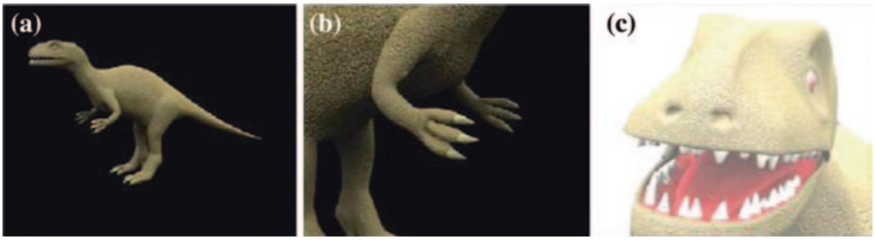

Fig. 6.4 Project "How did Allosaurus hunt" was showcased at the 40th annual conference of the international simulation and gaming association

3D Digital Science Arts Exchange which was held in Shanghai in May 2008. Figure 6.4 shows the project "How did Allosaurus Hunt" which was (poster) presented at the 40th Annual Conference of the International Simulation and Gaming Association. At the 3D Learning Symposium held in April 2011, NJC made a presentation to share the 3D research and development.

6.2.3 Feedbacks

To collect feedback to review the effectiveness of the 3D programs, surveys were conducted and the results for 2011 were presented in this chapter. The breakdown of the students participating in the survey included a total of 11 participants who had completed the 3D photo-rendering workshop and 3D photos montage, and completed the 3ds Max animation workshop and 20-second video clip production.

In 2011, two NJC graduand trainers, three NJC graduated students, and one external trainer were involved in providing training opportunities for our students.

Table 6.1 summarizes the survey results with a high positive response: %Strongly Agree (%SA) and %Agree (%A) of 99.2 % with the exception of one student in question 10 which is considered a neutral question not relating to the program quality. With reference to the 4-point Likert scale reading, it posted a strong 3.7 value which was considered a very high and quality response rating.

6.3 NJC–KSA International Science Exchange Program

Going beyond just local and overseas programs, conferences, and competitions, 3D research programs are being used as a tool for collaboration with one of NJC's International Science Exchange partners, Korea Science Academy of KAIST.

Principally, the exchange program was designed with a strong emphasis on communication, exploration, and collaboration (Fig. 6.5). Participating students are encouraged to explore various fields of their interests from science to technology to culture through collaboration and team projects. Basic training is provided with the exchange program to enable students' exploration and collaboration.

Table 6.1 Student survey results from 2011 workshops

Question	SA	A	D	SD	NA	%SA	%A	%SA & A	4-point likert scale
#1	6	5	0	0	0	54.5	45.5	100.0	3.5
#2	6	5	0	0	0	54.5	45.5	100.0	3.5
#3	8	3	0	0	0	72.7	27.3	100.0	3.7
#4	8	3	0	0	0	72.7	27.3	100.0	3.7
#5	7	4	0	0	0	63.6	36.4	100.0	3.6
#6	7	4	0	0	0	63.6	36.4	100.0	3.6
#7	6	5	0	0	0	54.5	45.5	100.0	3.5
#8	5	6	0	0	0	45.5	54.5	100.0	3.5
#9	9	2	0	0	0	81.8	18.2	100.0	3.8
#10	8	2	1	0	0	72.7	18.2	90.9 (1 student)	3.5
#11	9	2	0	0	0	81.8	18.2	100.0	3.8
#12	10	1	0	0	0	90.9	9.1	100.0	3.9
Average	7.4	3.5	0.1	0.0	0.0	67.4	31.8	99.2	3.7

Question
1. I understand better how to do 3D photo rendering or 3ds Max animation
2. I can now confidently work on a 3D project
3. I appreciate having such outreach workshops/projects in NJC
4. I enjoy having such outreach workshops/projects in NJC
5. The trainer was competent in terms of his/her science knowledge and skills
6. The trainer taught me skills beyond what I learn in school
7. I enjoyed a good working relationship with the trainer
8. This workshop has increased my enjoyment of science
9. I have had a positive experience in the activity/program organized by NJC
10. I would not have had a similar experience in NJC without participating in this activity/program
11. I have benefited from this activity/program
12. I would recommend this attachment program to future batches of NJC students

The impact of globalization is calling for a profound change in education. To improve global competency, different nations respond differently through education reforms. Learning from different education systems may help students to prepare themselves better for globalization which has attracted the attention of educators today to examine the effects of technologies on knowledge [8]. Today, there is a trend to send students overseas under various international exchange programs. It is common to see university students during their international exchange program, (typically one semester), attend lectures and do labs at their foreign partner university to experience different ways of learning. These students have chances to immerse themselves in different cultures. For the high school, though international exchange is getting more and more popular, the design of the exchange program is often limited to culture-based immersion, language learning, or conference/symposium presentation.

Always attractive to exchange students, culture exchange is generic and thus suitable to all students. Through culture immersion, exchange students can learn different cultures of a foreign country, and make friends of different cultures during

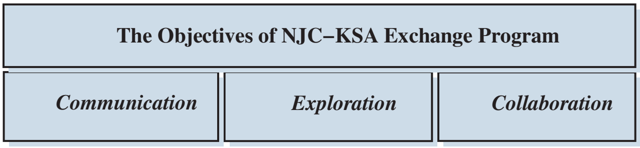

Fig. 6.5 The objective design of the NJC–KSA exchange program

various social activities of the culture exchange program. Today, culture-based immersion is the main form of international exchanges, especially for primary or secondary school students. While it is relatively easy to organize, this form of exchange has a disadvantage to integrate the curriculum in the exchange program.

Another common form of international exchange today is to send students overseas for attending competitions or grand challenges. Apparently, the exchange students can have a chance to meet up with fellow students from different countries. During the competitions or grand challenges, students from different countries may work together as a team addressing specific issues or developing specific solutions to problems set with the competitions or grant challenges.

6.3.1 Communication

Effective communication in a globalized knowledge economy today is essential. Exchange programs can provide the students with a common platform to freely communicate, interact, and share their ideas. More importantly, through this exposure of vast ideas from various sources with students of different backgrounds and essentially different cultures, it provided the students a global open mindset of different perspectives.

6.3.2 Exploration

The exchange program promotes the spirit of exploration. Students will be encouraged to explore different aspects of their interest from science to culture to nature. Through this exercise, they can develop their research interests in the specific field to search for diversity or commonalities from both schools.

6.3.3 Collaboration

Team spirit development is another major objective of this exchange program. Students will share their ideas, not just during the 2-week period of hosting and visiting by either parties, but will also be able to share their findings through other media technology means such as videoconferencing or e-mails. This concerted effort brings synergy to the research scope and goes beyond the physical boundary.

Table 6.2 Student survey results from 2011 KSA of KAIST–NJC workshop

Question	SA	A	D	SD	NA	%SA	%A	%SA & A	4-point likert scale
#1	4	6	0	0	0	0.0	60.0	100.0	3.4
#2	2	8	0	0	0	0.0	80.0	100.0	3.2
#3	3	6	1	0	0	0.0	60.0	90.0	3.0
#4	3	6	1	0	0	0.0	60.0	90.0	3.0
#5	4	6	0	0	0	0.0	60.0	100.0	3.4
#6	4	6	0	0	0	0.0	60.0	100.0	3.4
#7	3	6	1	0	0	0.0	60.0	90.0	3.0
#8	2	5	1	2	0	0.0	50.0	70.0	2.3
#9	3	6	1	0	0	30.0	60.0	90.0	3.0
#10	4	5	1	0	0	40.0	50.0	90.0	3.1
#11	2	7	1	0	0	20.0	70.0	90.0	2.9
#12	3	6	1	0	0	30.0	60.0	90.0	3.0
Average	3.1	6.1	0.7	0.2	0.0	30.8	60.8	91.7	3.1

Question
1. I understand better how to do 3D photo rendering or 3ds Max animation
2. I can now confidently work on a 3D project
3. I appreciate having such outreach workshops/projects in NJC
4. I enjoy having such outreach workshops/projects in NJC
5. The trainer was competent in terms of his/her science knowledge and skills
6. The trainer taught me skills beyond what I learn in school
7. I enjoyed a good working relationship with the trainer
8. This workshop has increased my enjoyment of science
9. I have a positive experience in the activity/program organized by NJC
10. I would not have had a similar experience in NJC without participating in this activity/program
11. I have benefited from this activity/program
12. I would recommend this Attachment Program to future batches of NJC students

The survey results in Table 6.2 show high positive response %Strongly Agree (%SA) and %Agree (%A) of 91.7 %. With reference to the 4-point Likert scale reading, it posted a relatively strong 3.1 value.

6.3.4 The Program Elements

With a clear mind about the target to achieve with the program, we then look into a detailed design of the program elements. Teaming is conducted at the very beginning of the program. Each team typically consists of 10 members from NJC and 10 from KSA of KAIST. Good teaming enables effective communication and effective collaboration. Basic training is provided to all students allowing them to gain fundamental knowledge and learn basic skills quickly. Hands-on projects are then carried out for scientific, cultural, or natural exploration within each of the student teams through collaborative efforts. At the end of the program, students are

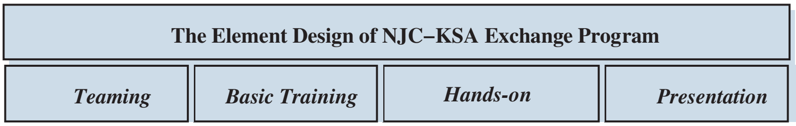

Fig. 6.6 The element design of the NJC–KSA exchange program

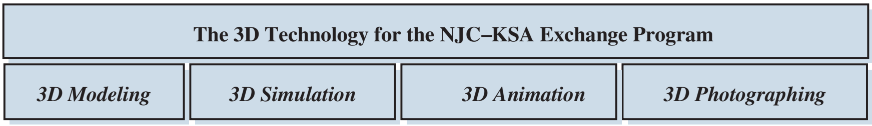

Fig. 6.7 The 3D technology for the NJC–KSA exchange program

required to do a team presentation summarizing their findings and reflections with the program (Fig. 6.6).

6.3.4.1 The 3D Technology

A niche part of this exchange program is the injection of 3D technology which has a base in mathematical and cognitive science. A basic 3D training course is conducted to teach students fundamental knowledge and skills in modeling, simulation, animation, and photographing. Using 3D technology, students can visualize their ideas or their findings of their exploration (Fig. 6.7). 3D Technology can also help the students while doing their presentation at the end of their projects.

6.3.4.2 The Discovery Journey

Over the years, three exchange programs have been designed. While all the programs share the same objectives, each time the programs were designed as different discovery journeys (Fig. 6.8). For instance, an exchange program can be a journey for students to discover the cultural differences between Singapore and Korea, to discover the extinct dinosaurs, or to discover the beauty of nature.

In the following section, three case studies will be discussed.

6.3.5 A Journey of Culture Discovery

The 2007 NJC–KSA exchange program was designed with a special focus on culture discovery. A total of 18 students (9 from each side) participated in the exchange program and were grouped into 4 teams. After teaming, 3D training was

Fig. 6.8 The different journeys of discovery

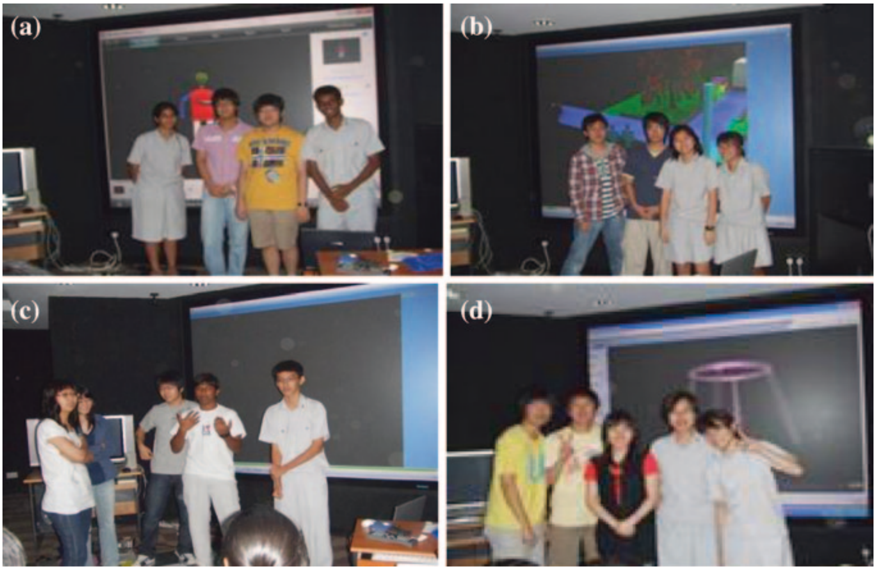

Fig. 6.9 Discovery of the cultural differences between Singapore and Korea. **a** Food culture, **b** Driving left side or right side, **c** Pirates of drift, **d** 3D animation of the fortune fountain

provided immediately to teach students the basic skills for 3D modeling, simulation, and animation. Team 1 did a 3D design and simulation of a Kimchi Eating Robot (Fig. 6.9a). Team 2 modeled the different ways of driving in Singapore and Korea (Fig. 6.9b). Team 3 worked on Pirates of drift (Fig. 6.9c). Team 4 developed a 3D animation for the Fortune Fountain in Singapore's SUNTEC City (Fig. 6.9d).

6.3.6 A Journey of Dinosaur Discovery

The 2008 NJC–KSA exchange program was designed as a journey for dinosaur discovery. Again 18 students (9 from each side) participated in the exchange program and were grouped into 9 teams. This time, each team had one Singapore student and one Korean student. 3D training was provided to teach students the basic skills for 3D photographing. The students then moved to Singapore Science Centre

Fig. 6.10 A journey of dinosaur discovery

for them to visit a public exhibition on dinosaurs. Before that, each of the project teams spent a day building their basic knowledge of dinosaurs through Internet study and project discussion. Using their digital cameras, students captured different types of dinosaur models for the production of 3D photos of dinosaurs with the aid of the skill learned at the training course (Fig. 6.10).

6.3.7 A Journey of Nature Discovery

The 2011 NJC–KSA exchange program was designed as a journey of nature discovery. In particular, trees, flowers, and leaves were identified as learning objects. A total of 20 students (10 from each side) participated in the exchange program and were grouped into 5 teams. 3D photographing training was conducted on day 1 to teach students basic 3D photo capturing. Each project team then started their investigation on plant biology. They spent the next whole day in the Hort Park to capture photos of trees, flowers, and leaves of their interest. (Fig. 6.11) shows some of the final results after 3D rendering.

6.4 Conclusion

This chapter presented the developmental stages, challenges, and successes of 3D development in the National Junior College. The 3D development includes the ideology and motivation for such a development and the design of the innovative program for International Science Exchange with its overseas partner. The 3D technology elements designed for the various programs and the International Science Exchange program are imbued in this chapter.

The biggest challenge foreseen is the proliferation of awareness of and application of 3D technology into everyday lessons, research, and for aesthetics purposes for both students and teachers. The building of capability and knowledge can be easily attained within 1–2 years of the 6-year Integrated Program (IP). The level of understanding of the benefits of this 3D development is not high and to allure

Fig. 6.11 Nature discovery in Hort Park

more teachers to take part in the 3D development is an uphill task as a typical 3D animation video product takes a few months to complete.

The dependence on 3D glasses and special observation positions and human fatigue are some of the existing problems that cause current 3D display systems to be expensive and cumbersome. Hence, this is recommended to be a future development area [6]. However, this can be resolved with the identification of able 3D research team drivers and strong external partnership support.

The other challenge is the lack of 3D animation opportunities to showcase the students' work such as existing long-term sustainable 3D local and overseas competitions and conferences. This will provide strong motivation for future development in this area, starting from younger students in the Secondary to the High School level.

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Chapter 7
3D System for Learning Gains in the Lower Secondary Normal (Technical) Stream

Clara Jieying Wang, Angeline Swee Ling Low and Cui Shan Woo

Abstract There is an emerging trend that the virtual learning system (VLS) has the ability to help learners learn better. With the increased immersion, interaction , and imagination that a three-dimensional (3D) VLS provides, it acts as an effective learning platform to ease teaching and learning problems especially for students who are academically at risk. This study investigates what features are needed in a 3D VLS to motivate learning for the topic on Digestion for Secondary 1 Normal (Technical) students in Singapore. Furthermore, it also explores how learning in the 3D VLS affects students' attitudes and achievements. Observations would also be made to see if the students have gained any twenty-first century skills such as self-directedness and collaboration. It was found that students gained an average of seven marks in their posttest, and that tasks that were collaborative in nature led to increased student academic efficacy. Findings also suggest that 3D simulation games accompanied with Twitter made the difference in motivating the students best as compared to the other features in the VLS as students were motivated to be engaged in more academic discussions. The authors also noted a slight improvement in students' self-management skills and analytical thinking, which suggests that the VLS helps to promote the development of essential twenty-first century skills.

Keywords Virtual-reality /learning environment • Three-dimensional games • Twenty-first century skills • Self-directedness • Collaboration • Cognitive gains • Normal technical • Low ability • Immersion • Interaction

7.1 Introduction

More often than not, as educators, we tend to expect our students to learn 3D in a 2D perspective and expect them to understand, assimilate, and apply. Inevitably, we are creating a gap in learning between the students who are strong, spatially

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C. J. Wang (✉) · A. S. L. Low · C. S. Woo
Jurong West Secondary School, Singapore, Singapore
e-mail: Clara_WANG@moe.gov.sg

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and are able to map back to 3D, and those who find difficulty in doing so. The latter usually refers to the students like those from the Normal (Technical) (N(T)) stream. As a result, for topics that require such visualization of content, they tend to have difficulty in understanding and applying the knowledge.

7.1.1 Normal Technical Stream

The N(T) stream was established in 1994 to provide general education to the lowest scoring students of each cohort in Singapore [1]. In Singapore, students placed in the N(T) stream have been categorized as the students who are academically at risk. The N(T) curriculum is focused on strengthening students' foundations in English and Maths to prepare for the national GCE 'N' level examinations. The main intent is to provide these students with a more hands-on, experience-based pedagogy. However, Singapore's N(T) classrooms remain academically oriented and examination-driven [2]. The prominent features of the N(T) curriculum are worksheets, behavior and time-on-task management, drill and review, and there is less focus on the integration of subject matter, and the acquisition of metalanguages and analysis (Albright et al. 2008).

7.1.2 Three-Dimensional Virtual Learning System

The 3D Virtual Learning System (VLS) provides a medium that is 'richly immersive and highly scalable' [3]. It provides an environment that 'capitalizes upon natural aspects of human perception by extending visual information in three spatial dimensions' and that 'enables the user to interact with the displayed data' (Wann and Mon-Williams 1996, p. 833). This interaction promotes engagement. Results in past studies suggest that the 3D VLS has the potential to add value to learning as compared to 2D technologies that are used to deliver the same learning content [4]. That is because 3D VLS gets students interested in the learning and enables them to better visualize abstract concepts. The system used for this study comprised a desktop virtual-reality system (VRS) and an immersion system which was used only for the teacher's demonstration. The use of the desktop VRS was more prevalently used in the intervention because of its cost, availability, and flexibility which makes it easier to adopt and be adapted by the teacher and students.

Learning can occur in many forms and a critical feature is in reinforcing a concept that is taught in class. This is one of the key affordances of this 3D VLS. When 3D VLS is matched with the lesson concepts, it not only equips the teachers with better capacity to facilitate the learning but also benefits the students' learning immensely. In a study by [7], students involved in the 3D virtual learning environment (VLE), River City, achieved 16 % higher scores in the posttest than

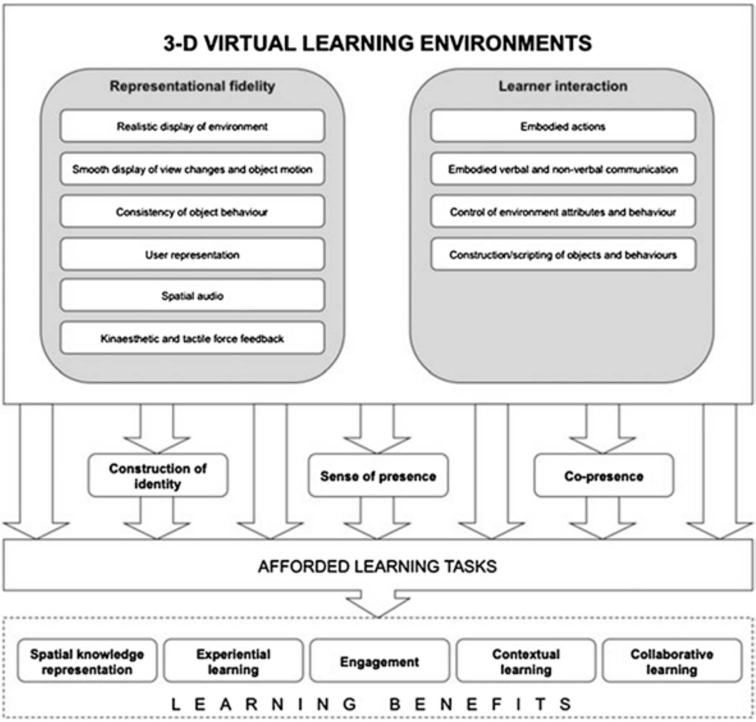

Fig. 7.1 Elaborated model of learning in 3D VLEs [10]

those who were in the paper-based control group. 3D VLE motivates learning. This could be seen from the implementations of River City in public school classrooms which showed that both male and female students were highly motivated as a result of using the 3D VLE [8]. In fact, the study showed that there was a greater positive impact on learning for low-achieving students in the inner city schools [9]. Similarly, another study in SciCentr outreach programme demonstrates that significant amount of learning can take place in a virtual environment, students rate the experience higher and a mix of modalities is a powerful way to build students interest and self motivation [10].

The strengths in 3D VLE are as shown in Fig. 7.1. The benefits of representational fidelity and learner interaction in 3D VLE have the potential to bring about useful learning benefits. Engagement in the medium will motivate students. That is a powerful factor to enhance learning. When students are exposed to direct experience of the context and are engaged in it, they have the potential to understand the concepts better [11]. According to [12], the longer the content stays in short-term memory, the higher the chances that will be able to build a stronger association with the long-term memory. So when students are motivated to interact with the content, they can work it into their memory better. This encourages enduring understandings.

7.1.3 3D Simulation Gaming

The inherent pedagogical qualities of games [14] have led to heighten interests to create games that can successfully intertwine with learning goals. Large numbers of educators around the world are interested in harnessing the educational power provided by the interactive engagement afforded by 3D games with the photorealistic effects. They are excited at the prospect of 'co-opting' [15] the tools and toys that students already use for communication and entertainment to help them learn better. Empirical evidence has shown that games can be effective tools for enhancing learning and understanding of complex subject matter ([16]), and can foster collaboration among learners [17]. Collaborative learning here refers to the online collaboration, where students share their knowledge, discuss their points, and try to negotiate for a common understanding. Making learning fun for most students increases their motivation through active learning or learning by doing [18]. Furthermore, the learner needs to learn not only how to understand and produce meanings in a particular semiotic domain that are recognizable to those affiliated with the domain, but, in addition, how to think about the domain at a 'meta' level [14]. The visual and hands-on environment made possible with 3D simulation gaming brings about the potential for learners to think more at a 'meta' level, achieve cognitive gains, promote deeper thinking, and develop life skills for the twenty-first century, such as analytical thinking, team building, multitasking, and problem solving under duress [19] as a result of its interactivity.

There are a number of researchers [14, 20] who have documented positive educational outcomes, but there is little conclusive evidence that attests to the specific learning benefits of gaming in 3D VLEs, and not for one that is coupled with the use of Social Media. In this new century, the overlaps between new media and media interfaces are becoming significant as game technologies and practices are 'becoming more pervasive as commonplace social practices' ([21], p. 11). There is potential that the features in Social Media can increase the immersion, interaction, and imagination needed to enhance the educational experience in a VLE. So adding elements of such into lessons, promises the increase in students' motivation to learn and to influence the learners' attitudes, skills, and achievement in a positive way.

7.1.4 Social Media

The virtual social interaction provided by Social Media is often associated with the Community of Practice (CoP). They are 'technologies that enable communication, collaboration, participation, and sharing' [22], where 'parallel realities and extensions of the social environment that allows students to interact virtually' [23] occur. In Social Media, learners act as content creators and networking actors. Lave and Wenger [24] claimed that it is critical that participants in CoPs must have a shared domain of interest and shared goals to enable them to build relationships and learn from one another. This is taken into account for this study. Several studies state that social network tools support educational activities by making interaction, collaboration, active participation, information and resource sharing, and critical thinking possible ([25, 26, 27]. This shows that Social Media tools are good communication tools that can be leveraged on for learning purposes as it gives students a voice and opportunity to interact with others as their thoughts are externalized. There is potential in knowledge sharing based on social networks [28], to bring about collaborative learning and perhaps even promote self-direction and deep learning. Coupling this with the visual and hands-on environment made possible by the 3D VLE, the learning experiences of our students can be greatly enhanced.

7.2 Method

7.2.1 Participants

Twenty Secondary 1 N(T) students took part in this quasi-experimental study. There were 7 girls and 13 boys. Their Primary School Leaving Examination (PSLE) results range from 121 to 150 and their Science grades are C and below. The maximum score for this examination that consists of 3 subjects is, 300, and the pass mark for each subject is 50. The use of computers was an integral part of classroom practice.

7.2.2 Research Questions

During the sessions, students were involved in different 3D features comprising a short movie, poster, and simple simulation games and with and without the use of Twitter. Thus, the main questions that we seek to address in this study are:

(1) What are the essential features needed in a 3D VLS for secondary 1 N(T) students to be motivated to learn?
(2) Does the 3D VLS promote student achievement, attitudes toward the subject, attitudes to use of ICT, and academic efficacy?
(3) Is there a significant relationship between the various classroom environment dimensions in the Technology-rich Outcomes-focused Inventory (TROFI) survey (i.e., student cohesiveness, teacher support, involvement, investigation, task orientation, collaborative learning, equity, virtual environment, young adult ethos, attitude toward subject and computer) and academic efficacy?

7.2.3 Measures

The pre and posttests consisted of items that test students for their understanding of the knowledge gained. 25 % of the questions were based on recall, 25 % on understanding, 40 % on how well students could handle, apply and communicate information, and the last 10 % on higher order thinking. The posttest was given 2 weeks after the intervention.

A TROFI is used in this study to investigate the effects of the intervention on the following classroom environment dimensions: student cohesiveness, teacher support, involvement, investigation, task orientation, collaborative learning, equity, virtual environment (only about 3D), young adult ethos, student affective outcomes, and academic efficacy. Student affective outcomes were measured in terms of their perceptions of their achievement for the subject and attitude toward the new learning environment. The TROFI consists of 12 underlying scales (8 items per scale). Each item employed a 5-point Likert response format (Almost Never = 1, Seldom = 2, Sometimes = 3, Often = 4, Almost Always = 5) with items scores aggregated to form scale scores for each respondent and is deployed over the school's learning management system.

The qualitative measurement consisted of lesson observations and a post interview with the students. Students were tracked on how well they managed themselves in class, the timeliness of doing their after-lesson assignments, the kind of answers they gave for their assignments, and their discussions on Twitter.

7.3 Results and Discussion

As seen in Table 7.1, there was an average gain of about seven marks per student after the intervention. The standard deviation remained rather constant. Nine individuals who took a more active role in the intervention tend to score better in the posttest as compared to their pretest, they scored 2–3 times better (e.g., from 8/30 to 21/30 or improved in at least 7 marks). A paired *t*-test between the pretest and posttest reveals that it is significant at the 0.05 level.

The mean TROFI scale results are as shown in Fig. 7.2. Figure 7.2 indicates the following findings: scale means for student cohesiveness, involvement, task orientation, investigation, collaborative learning, equity, virtual environment, attitude toward subject and computers and academic efficacy. Most of the scale means

Table 7.1 Pretest and posttest marks

	Mean	No. of students	Std. deviation
Pretest	10.75	20	3.596
Posttest	17.55	20	3.845

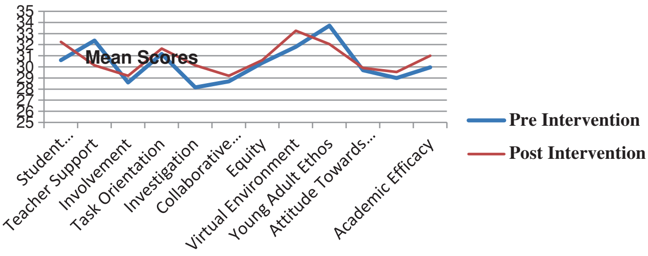

Fig. 7.2 TROFI Mean scores for 12 scales

Table 7.2 Correlation coefficients of scale

Environment scale	Correlation to academic efficacy
Student cohesiveness	0.035
Teacher support	–0.112
Involvement	–0.274
Task orientation	0.149
Investigation	0.149
Collaborative learning	0.606 *
Equity	0.543
Virtual environment	0.172
Young adult ethos	0.038
Attitude toward subject	0.303
Attitude toward computer	–0.139

were higher in the posttest other than teacher support and young adult ethos. The biggest positive gains are found in student cohesiveness, investigation, and academic efficacy.

Student cohesiveness is found to be significantly negatively correlated to investigation, −0.646 (Table 7.2). Although both student cohesiveness and investigation are positively correlated to academic efficacy, 0.035 and 0.149, respectively, they are not significant. This suggests that as students embarked on more investigative activities, their cohesiveness diminishes and that may or may not translate to better academic efficacy. More in-depth and larger scale studies would have to be carried out in order to determine the exact relationships between these variables. Collaborative learning, however, was found to be positively significant to academic efficacy at the 0.05 level with a correlation coefficient of 0.606. This shows that when students are engaged in tasks that are collaborative in nature, there is better academic efficacy for that topic or subject. This implies that the way the lesson is planned has to take into account the nature of the tasks in order to be effective for learning; in this case, collaborative tasks make a difference to learning. Teachers need to rethink traditional notions of teaching and include activities and allocate time for students to be engaged in positive interdependence even for students who tend to be disruptive or for those who are academically at risk. The attitudes toward the subject and attitudes to use of ICT, however, do not show any significant relationships with academic efficacy.

During the post interview, students described the nature of tasks as “Fun, interesting, especially, the use of games”, “Lessons are different”, and “Learn through games, good”. They also commented on the resources given saying that “Questions in worksheets let me know what we need to learn” and “must be accompanied with teacher’s explanation”. Students are more motivated in online, collaborative discussions after the 3D games rather than with 3D posters or 3D movies. That could possibly be due to the differences in the interactivity levels of the 3D features. They were noted to have particular interests in the use of Social Media during and after lessons as more than three-fourth of the class responded positively to it and had constructive threads. Some comments from the students were, “The use of twitter after an activity is important, so others know what I know”, “I can show off what I know”, and “Just in case I am wrong, someone can correct me”. This corresponds to quantitative results that highlight the significance of positive interdependence among the students. Discussions on Twitter revealed that students encouraged each other to work hard and to complete their assignments and attend lessons: “don’t disturb me I need to do homework” and “just go see a doctor and come to this 3D I don care even I sick”. More mental effort is seen to be placed during the course of this intervention (Figs. 7.3 and 7.4).

When asked about how the experience was between using 3D as compared to 2D representations, students said, “With 3D, I can see the organs which one in front, which one at the back”, “so real, I tried to put my hands through” and “Now, I can see how the whole thing is”. During the lesson with the 3D poster, it was observed that many students tried to pry their hands through the poster and with associated activities to link with that experience; they were able to relate the sequence of the main digestive organs and accessory organs well. They also displayed understanding of the relationships and functions between the main digestive organs and the accessory organs better than students who learnt the same topic using conventional methods the year before. Students were also observed to be more attentive; those that tend to be disruptive in class were observed to have behaved well. They were on task most of the time, and they took part in more

Fig. 7.3 Photograph of students exploring the digestive system using the 3D poster

Fig. 7.4 Photograph of students engaged in the 3D game

academic conversations as the lessons progressed especially during and after the use of 3D games. There was also an improvement in some students' self-management skills such as being able to set their own simple goals, checking for their own understanding, initiating discussion of content learnt, and negotiating with other students. In order to externalize students' learning, they were required to draw mind maps to show their learning. About 60 % of the students drew detailed mind maps which were on par with the standard of what Express students (students of higher academic achievements with PSLE score of above 190) would produce in the school.

So it can be seen that features needed for a 3D VLS to be conducive for learning will include good 3D visualization representations, an interactive response system such as simulation gaming and an online communication platform for students' views to be expressed. In fact, a few students suggested adding pop-up fact boxes to explain the consequence of their actions in the games at different intervals of the game to help them in the understanding of the topic. Tasks would also have to be collaborative in nature.

7.4 Conclusion

From the results, we can see that in this study, eight classroom environment scales (student cohesiveness, task orientation, investigation, collaborative learning, equity, virtual environment, young adult ethos, and attitude toward subject) could be explanatory variables in the final academic efficacy. Collaborative learning is the only explanatory variable that is significant. The main limitation for this study is that it provides little basis for generalization due to the small sample size. However, this research is still noteworthy as the study shows a significant positive effect for collaborative learning with academic efficacy. This shows that it is crucial for activities to be collaborative in nature to bring about improvement in academic efficacy and performance. Interactive 3D games may be the platform for students who are academically at risk to be engaged as results show that through the 3D games, there were more academic discussions among the students. It is essential to note that 3D simulation games have to be coupled with appropriate pedagogical approaches for effective learning.

Reflecting from what we have learnt from this study, we realize that constant probing by teachers and demonstrating how students should ask questions online and offline can help to garner more quality discussions. In addition, specific rules should be set on how one should behave in a CoP. A combination of the 3D features with the Social Media element in one common platform may increase the ease at which the technology is used and make learning more effective. Future studies to explore the different Social Media elements can be done to see which pairs best with the 3D VRS and the immersion system. Future developments for the game can also include co-creating game features with students to develop their critical thinking skills.

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Chapter 8
Learning Activity System Design for Autistic Children Using Virtual Pink Dolphins

Noel Kok Hwee Chia, Yiyu Cai, Norman Kiak Nam Kee, Nadia Thalmann, Bianyue Yang, Jianmin Zheng and Daniel Thalmann

Abstract Since the identification of the first cases of Autism Spectrum Disorder (ASD) in 1943 by Dr Leo Kanner, the number of reported ASD cases as well as research studies expanding our understanding of the disorder has increased rapidly and significantly. In terms of ASD treatment, there is a wide range of conventional as well as complementary and alternative interventions. Since the beginning of the new millennium, interest in Virtual-reality (VR) technology within the domains of special education and neuro-rehabilitative medicine has been growing rapidly. Today, the VR application research studies have offered more opportunities and a wider scope for developing innovative autism treatment. This chapter presents one VR application in autism treatment using artificial agents or bots (3D virtual pink dolphins) in a virtual environment (3D dolphinarium) through an interdisciplinary collaboration among engineering, new media, arts, and education at the Nanyang Technological University, Singapore. The collaborative effort has resulted in the development of the Learning Activity System Design for autistic children using virtual pink dolphins to serve as a platform for future development in the VR-based autism treatment.

N. Chia · N. Kee
National Institute of Education, Nanyang Technological University,
Singapore, Republic of Singapore
e-mail: kokhwee.chia@nie.edu.sg

N. Kee
e-mail: kiaknam.kee@nie.edu.sg

Y. Cai (✉) · N. Thalmann · D. Thalmann
Institute for Media Innovation, Nanyang Technological University,
Singapore, Republic of Singapore
e-mail: myycai@ntu.edu.sg

Y. Cai · B. Yang
School of Mechanical and Aerospace Engineering, Nanyang Technological University,
Singapore, Republic of Singapore

J. Zheng
School of Computer Engineering, Nanyang Technological University,
Singapore, Republic of Singapore

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8.1 Introduction

Since the identification of the first cases of Autism Spectrum Disorder (ASD) in 1943 by Dr Leo Kanner [1], the number of individuals diagnosed with autism has increased drastically from 2–4 per 10,000 births in the 1990s to 60–116 per 10,000 births in the 2000s [2–4]. As a result, many countries, especially those in Europe and North America, have channeled their resources into research to address the autism epidemic in two main aspects: (1) to understand the onset and causes of autism in order to develop better diagnostic screening tools; and (2) to determine the effectiveness of a wide range of intervention strategies to treat autism.

This chapter reports the latest research with the Virtual Pink Dolphin Project, an interdisciplinary collaboration among engineering, new media, arts, and education. Our interest is to develop novel Virtual-reality (VR) technology, and to design VR technology-enabled learning system for autistic children. Section 8.2 introduces the ASD. Section 8.3 details the learning difficulties with autistic children. Section 8.4 discusses VR-enabled technology with a focus on the development of Virtual Pink Dolphins. Section 8.5 presents the activity system design with the aid of Virtual Pink Dolphins for autistic children's learning. Section 8.6 concludes this research.

8.2 Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is a neuro-developmental syndrome with signs and symptoms collectively indicated or characterized by qualitative impairments in social interaction and communication as well as the presence of restricted, repetitive, and stereotyped patterns of behaviors, interests, and activities [5]. The International Classification of Diseases-Tenth Revision [6] uses Pervasive Developmental Disorders (PDD) to refer to ASD. Hence, the medical professionals have also frequently referred ASD to PDD. However, in the Educator's Diagnostic Manual of Disabilities and Disorders [7], the term ASD encompasses a range of disorders that include Asperger syndrome, autistic disorder, Rett's syndrome, childhood disintegrative disorder, high-functioning autism, hyperlexia, multiplex developmental disorder, and pervasive developmental disorder not otherwise specified (PDD-NOS).

Recent studies [8, 9] suggest that though individuals with ASD display empathizing deficits, they have intact or even superior systemizing ability to analyze and build systems so as to understand and predict the functional behavior or impersonal events or inanimate or abstract entities. Myers et al. [10] have listed the following six systems: (1) mechanical systems such as machines and tools; (2) natural systems such as biological processes and geographical phenomena; (3) abstract systems such as mathematical concepts and computer programs; (4) motor systems such as 3D drawing, piano finger technique, or a lawn tennis shot; (5) organizable systems such as Dewey Classification System used in library cataloging of books or stamp collection; and (6) social systems such as a business management or a football team. The way an individual with ASD makes sense of any of these systems is not in terms of mental states, but in terms of underlying rules and regularities. As a result, individuals with ASD think and perceive very differently from those are non-autistic. This has been termed as autistic logic [11]: a kind of reasoning system that someone with ASD processes, basing on his/her *own* understanding of daily conspicuous happenings and eventful experiences, and making use of this understanding to construct his/her *own* new understanding of what he/she still observes and/or experiences, with a tendency to view life in terms of his/her *own* needs and desires. This can result in some kind of autistic *savoire-faire*. Hence, an individual with ASD tends to be rather rigid, ritualistic, or structured in the way he/she thinks and does things. Such superior systemizing ability can be seen in those termed as autistic savants, who may have two or more savant abilities [12].

However, there is also another lesser-known sub-group of autistic crypto-savants, who, "because of their inability to communicate, have savant skills that are hidden, or secret, and unknown to those around them" [13]. Chia [14] has argued that ASD is an neuro-developmental syndrome of constitutional origin (genetic) and whose cause could also be epigenetic, and its onset is usually around first 3 years of birth, with empathizing or mentalizing deficits that result in a triad of impairments in communication, social interaction, and imagination (or presence of stereotyped behaviors), but may, on the other hand, display (especially by autistic savants) or hide (especially by autistic crypto-savants) a strong systemizing drive that accounts for a distinct triad of strengths in good attention to detail, deep narrow interests, and islets of ability.

8.3 Learning Difficulties with Autistic Children

ASD Learning difficulties and behavioral challenges have been investigated by many researchers including Siegel [15] and Chia et al. [16]. Studies [16–19] have identified three main domains of mental potentials: cognition [20], conation [21], and affect [22], and in each of them, there is a specific typology of learning and behavioral skills and abilities [23]. Children with ASD display deficits or dysfunctions in all of these three domains to some degree of severity.

Cognition, according to Poland [18], "has to do with intellect, the 'use of the mind,' whether it is logical or illogical. Thinking is not directly observable, although an individual human may experience within himself or herself what is called thinking". Bloom et al. [20] have identified six levels of mental skills, i.e., knowledge → understanding → application → analysis → synthesis → evaluation, and more recently, revised by Anderson et al. [24], whose cognitive domain includes remembering → understanding → applying → analyzing → evaluating → creating.

Conation is a term that has been used by classical psychologists to refer to willingness, desire, or a striving toward achieving goals [25]. Today, the term is often ignored by most educators in academe [19]; Snow et al. [26] at the same time, is also being confused with psycho-motion. Psycho-motion is associated with skilled behavior; conation, with action. Psycho-motion is concerned with the physical skills to perform a given task, while conation concerns if the person possesses the will, desire, drive, level of effort, mental energy, intention, striving, and self-determination to actually perform to his or her very best [19].

According to Poland [18], conation is referred to the inherited potential for action. "We inherit bodies that are able to move, awkwardly and ineptly at first, but with a growing and developing smoothness and skill as the years pass. Actions are observable behaviors such as dancing, laughing, talking, simply sitting in a chair, or pole vaulting. Actions are sometimes referred to as conative behavior, which can include a great variety of automatic behaviors such as walking and habits such as smoking or repeatedly wiggling a foot while sitting in a chair" (p. 13).

Riggs and Giholar [21] highlighted six attributes in the fundamental framework of conation: belief → courage → energy → commitment → conviction → change. Parkison [17] has simplified the framework into four levels of mental skills (since conation creates changes from within): personal discovery → transition → transformation → transcendency.

Krathwohl et al. [22] have provided the best-known affective domain taxonomy, which is ordered according to the principle of internalization. Internalization refers to "the process whereby a person's affect toward an object passes from a general awareness level to a point where the affect is *internalized* and consistently guides or controls the person's behavior" [27]. Krathwohl et al. [22] have listed five levels of affective attributes: receiving → responding → valuing → organization → characterization by value.

According to Poland, affect concerns feeling that is the genetically based potential (also known as affective behavior) and "it has to do with a wide variety of behavior ranging from sadness and depression through happiness and ecstatic joy. Feelings are not directly observable, although they often may be expressed through action" (1974).

When conation and affect are brought together, it forms what is known as *orexis*, a Greek word, which means the conative and affective character of mental activity as contrasted with its cognitive aspect. It is often referred to the appetitive aspect of an act in order to satisfy some psychosomatic desire (e.g., love and sex).

In the field of special education, the cognitive domain is often referred to the intellectual aspect of the mind that concerns with acts of learning and thinking, while conative and affective domains are referred to the feeling and striving aspect of the mind or of a socio-emotional behavioral act [16]. Figure 8.1 illustrates the triangulation of cognition, conation, and affect. However, the model is incomplete without sensation or sensory domain, which links all the other three domains together.

According to Chia et al. [16], sensation consists of two systems: interoceptive and exteroceptive senses. The interoceptive sensory system is made up of two senses: vestibule and proprioception. The exteroceptive sensory system consists of five sensory organs: eyes, ears, skin, nose, and tongue (see Fig. 8.2).

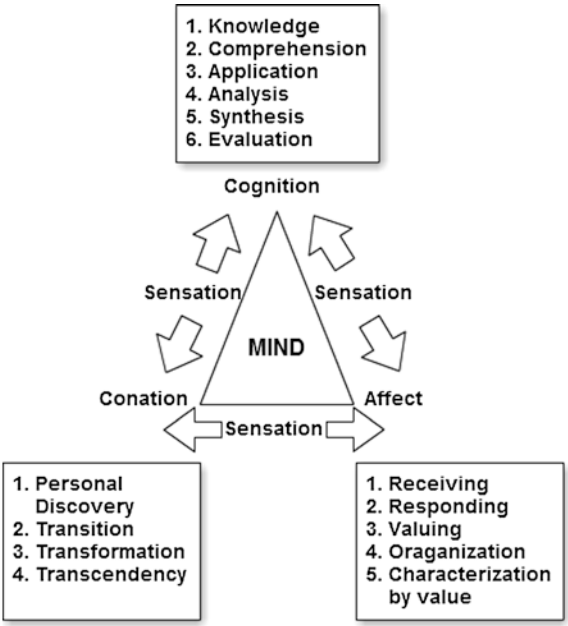

Fig. 8.1 Triangulation of cognition, conation and affect [16]

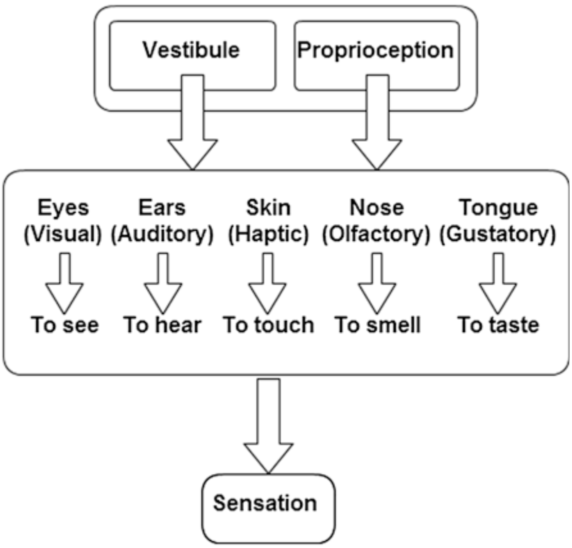

Fig. 8.2 Interoceptive and exteroceptive sensory systems

How sensation goes about processing and making sense or comprehending sensory inputs, and thus its impact on the motor coordination and motor outputs (i.e., motions and movements) depends on its involvement with cognition, conation, and affect as follows [16]: (1) the sensation between affect and conation involves self-awareness and self-regulation, respectively; (2) the sensation between cognition and conation involves self-learning and self-regulation, respectively; and (3) the sensation between affect and cognition concerns self-awareness and self-learning, respectively. It is beyond the scope of this chapter to delve into detail on this topic. Generally, many children with ASD also manifest deficits/dysfunctions in sensation resulting in what has been termed as sensory processing disorder and its related sensory anomalies.

8.4 Virtual Pink Dolphins Assisted Learning Activity System Design for Autistic Children

The onset of ASD often comes with manifestation of developmental delays in many skills such as communication and social interaction and such children lack the ability to see imagination. In many cases, children with ASD also have sensory processing difficulties that often hinder their sensory perceptual motor responsivity to the immediate environments where they are in. As a result, many fail to respond when their names are called (auditory), show a lack of joint attention (visual), display self-stimulatory behaviors (haptic motor) and make meaningless neologic utterances (auditory/aural–oral).

These children with ASD feel more comfortable with repetitive behaviors, which can go on for hours, and are quite resistant to changes and/or new situations as these create anxiety and tension for them. They are also found to be hypersensitive to sounds with high pitch and prefer low pitch humming ones. A few studies [28–30] have been done to show that ambient sounds help individuals with ASD understand the environment they are in. Ambient sounds provide a steady source of sounds that are not generally nerve-jarring. These sounds, for some children with ASD, are simply constant and rather soothing and help them to stay calm and concentrate on what they are engaging at that point in time [31]. However, there are also other studies [32–34] suggesting that it is still inconclusive to confirm the effectiveness of sound therapies such as Auditory Integration Training and SOMANAS therapy as autism treatment.

In view of the problems displayed by children with ASD, there is a need for an appropriate learning activity system (LAS) designed to meet their learning and behavioral needs in order for them to benefit from a treatment they are to undergo. By LAS, it refers to a collective construction that is not reducible to discrete individual actions [35]. It can be any continuous, goal-directed, historically conditioned, dialectically structured, tool-mediated human interaction, such as a treatment, an individualized education plan, a program of study, a school, a family, and so on [36]. According to Holt and Morris [37], LAS is focused by the interaction of minds in the world, socially constructing and sharing meaning. To Engeström [38], LAS is made up of four main subsystems, i.e., production, consumption, distribution, and exchange, and it also contains the following interacting components, i.e., (1) subject; (2) object; (3) tools and signs; (4) division of labor; (5) community; (6) rules; and (7) the guiding agents/mediators. Engeström's model of LAS has been adapted by Jonassen [39] where a seventh component has been added to Jonassen's model.

The four learning activity subsystems describe the higher order functions, interrelationships between and among the components of the entire system [37, 39]. Each of these interacting components and subsystems are briefly described below.

8.4.1 Interacting Components of the Autistic Children'S Learning

8.4.1.1 Subject

This refers to any individual or a group of individuals engaged in an autism treatment. The subject possesses cognitive, conative, and affective behavioral potentials (interlinked by sensation) that are brought into the LAS.

8.4.1.2 Object

Objects of the autism treatment are results that are produced by the treatment. The transformation of the object into the desired outcome represents the purpose or intention of the treatment (Table 8.1).

8.4.1.3 Tools and Signs

They are the means that the subject uses for acting on the object. They can be anything used in the transformation process. According to Jonassen [39], "[T]he use of culture-specific tools shapes the way people (subject) act and think" (p. 100).

Table 8.1 Description of subsystems

Production subsystem	
Subject	Any child with ASD
Object	To initiate or prompt and sustain a dialog through functional sign language and respond to recorded or synthesized dolphin sounds
Tool	Immersive serious games
Signs	Functional sign language including gestures and recorded/synthesized dolphin sounds
Guiding agent	Virtual pink dolphins are used as the AI agents or bots
Consumption subsystem	
Community	Case manager, application/software designer, special education teacher, speech-language therapist, and educational therapist (these are some examples and they are not in order of importance/priority)
Distribution subsystem	
Division of labor	This depends on who the main person-in-charge is to delegate professional duties to the other professionals involved in this form of autism treatment
Exchange subsystem	
Rules	Code of ethics and professional conduct for the community

8.4.1.4 Community

This consists of the interdependent professionals as well as allied professionals (e.g., case manager, psychologist, occupational therapist, speech-language pathologist, educational therapist, counselor, and others who are involved in the treatment) who share a set of activities and their social meanings in the autism treatment. Within the treatment plan, the community functions to distribute professional responsibility among those involved as well as the kinds of formative/summative results expected.

8.4.1.5 Division of Labor

This refers to the horizontal division of tasks between cooperating professional members of the community but also to the vertical division of power and status [38]. "How flexibly any work organization can adapt to circumstances will determine the ability of the LAS to engage in different activities" [39].

8.4.1.6 Rules

They refer to the explicit regulations, conventions, policies, and the code of ethics and professional conduct that constrain the activities conducted in the treatment "as well as the implicit social norms, standards, and relationships among members of the *professional* community" [39] (word in italic is additional).

8.4.1.7 Guiding Agent/Mediator

This refers to anyone or anything that serves as a guide to lead the subject through the process of treatment to realize the object in order to attain the expected outcome.

8.4.2 Learning Activity Subsystems

8.4.2.1 Production Subsystem

This consists of "the objects that attempt to produce the outcome of the system" [39]. The outcome refers to the impact of the autism treatment on those for whom the treatment is intended. The outcome may be specified in advance (e.g., the learning goals/objectives of an individualized education plan or learning and behavioral goals of a treatment plan) or may be unintended results of the treatment design and/or implementation, and these results can be referred to as consequences. This subsystem involves a subject, the object of the autism treatment, the tools (e.g., visual cue cards) that are used in the treatment, and the actions and operations that affect an outcome [40]. Among all the four subsystems, the production subsystem is most important. This is because through the processes, the object of the LAS (autism treatment) is transformed into the desired outcome, i.e., the intentions of the treatment are manifest. According to Jonassen [39], the production subsystem "consists of interactions and relationships between the subject and object that are mediated by tools and signs" (p. 99) with the ultimate aim of transforming the object of treatment into a positive outcome.

8.4.2.2 Consumption Subsystem

This concerns how the subject and the surrounding community collaborate to perform according to the object of the autism treatment. The aim of the LAS is to transform an object of the autism treatment in order to attain the expected outcome (e.g., reduction in stereotyped behavior). However, it also takes up energy and resources from the subject and the community the subject is in. According to Jonassen [39], "[T] he subject has to operate within a community that reciprocally supports the production activities of the subject, but also consumes effort from the subject" (p. 101).

8.4.2.3 Distribution Subsystem

This subsystem ties the object of the autism treatment to the community (a group of professionals working together as a team) by defining a division of labor, i.e., it divides up the tasks according to the professional disciplines such as speech-language therapy, occupational therapy, and educational therapy.

8.4.2.4 Exchange Subsystem

This subsystem involves the subject and two contextual components: "the rules that constrain the activity and the community with which the subject interacts" [39] (p. 102). First, this subsystem regulates the tasks that are to be carried out in the treatment in terms of the subject's needs. Second, it also decides on which professionals to be involved in the autism treatment as required to cater to the subject's needs.

8.4.3 Virtual Dolphinarium Learning Environment

Figure 8.3 shows how LAS in the technologic application of AI agents or bots, i.e., virtual dolphins, is structured into a collaborative autism treatment involving a community of professionals with the use of VR technology. The 3D virtual dolphinarium is the context that serves as an external stimulus where various distractions

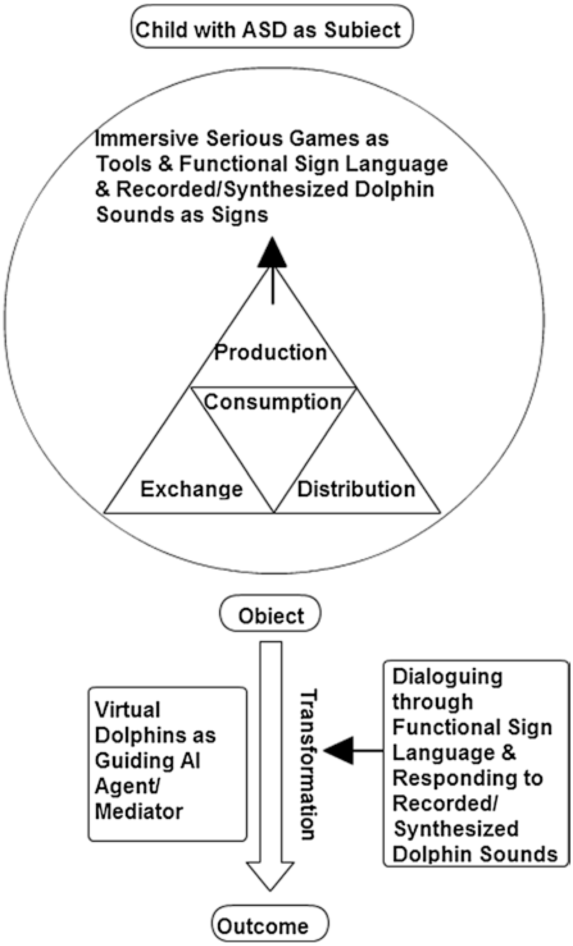

Fig. 8.3 Virtual Pink Dolphins as AI agents/bots in the LAS of technogogy

can be thrown into distract the subject. At the start of the treatment, a teacher or therapist would demonstrate to the child with ASD how to dialog with the virtual dolphins through use of simple hand gestures (a part of the functional sign language) to initiate/prompt a virtual dolphin to respond by performing certain antics (e.g., waving its flipper). As the child with ASD makes progress to acquire other gestures as well as respond to dolphin sounds, dialoguing with the virtual dolphins can become self-initiated and further sustained. In this system design, VR is used as the medium through which feedback or reinforcement is provided, rather than as the primary treatment tool itself [41]. For instance, if the learner successfully gets the virtual dolphin to perform a required act, he/she is immediately rewarded with the happy dolphin sound being emitted by the virtual dolphin. Alternatively, the learner can proceed to play another virtual game. On the contrary, if the learner fails to get response from the virtual dolphin after duration of, say, 1 min or so, the virtual dolphin will go to sleep at the bottom of the pool with "zzzzzz" being shown on the screen to indicate that the bored virtual dolphin has gone to sleep. To reactivate the virtual dolphin, the learner needs to call out loudly "Dolphin, wake up!" as he/she claps his/her hands twice. The gesture-based interaction system (already incorporated into the VR system) will capture the learner's gestures, which are then projected in real time into the virtual environment to facilitate dialog between the child with ASD and the virtual dolphin.

8.5 VR-enabled Technology using Virtual Pink Dolphins

8.5.1 Outline

The development of emerging technologies has made an increasing number of information and communications technology (ICT) tools widely available. While computer technology is changing the way we work and communicate with each other as well as the way we live today, 3D VR technology continues to revolutionize computer technology for various applications in medicine, education [42–45]. Recently, the new field of Virtual Rehabilitation has grown. The term Virtual Rehabilitation applies to both physical therapy [46] and cognitive interventions such as for patients suffering from executive function disorders [47], memory [48], attention deficits [41], Post Traumatic Stress Disorder [49], or phobias [50, 51].

As a result of the rapid technological advancement in the past two decades, it has become inevitable not to harness the prowess of ICT to foster learning and develop appropriate behavior. In fact, "ICT has been used to support learners with special needs in mainstream as well as special schools" [23]. Known as enabling or assistive technology, it has adapted to developments in technology as well as to education policy changes for learners with challenging or different needs [52].

There are certain conditions and impairments that are known to create barriers to learning and behavior unless appropriate accommodations are made or provided. The inventive use of technology becomes a key consideration for professionals caring for and working with individuals with special needs.

Known as *technology*, the term used by Idrus and McComas [53] refers to the transformative use of technology to foster learning and develop appropriate behavior. Idrus [54] has redefined technology as the convergence of technology, pedagogy and content in the transformative use of ICT to foster learning and develop acceptable behavior. According to Idrus, there exists a relationship between what is being taught (the subject matter or content), how it is being taught (pedagogy), and the appropriate technology that is used in teaching. Hence, there is an interplay of content, pedagogy, and technology as shown in Fig. 8.4. The symbol T stands for technology.

Koehler and Mishra [55] have argued that true technology integration concerns both understanding and negotiating the relationships between those two components of knowledge, and thereby creating a third component: techno-pedagogic content knowledge (see Fig. 8.5).

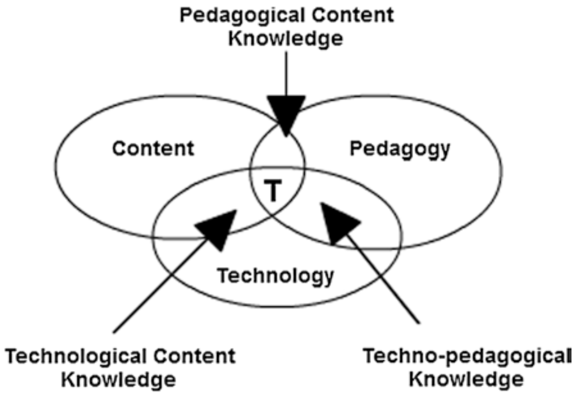

Fig. 8.4 Model of technology [54]

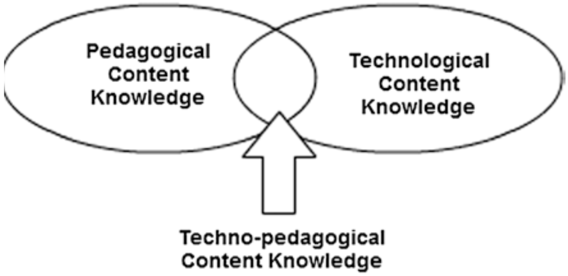

Fig. 8.5 Two-dimensional model of knowledge [55]

8.5.2 What is a Bot?

A bot is a device or piece of software that can execute commands, reply to messages, or perform routine tasks, as online searches, either automatically or with minimal human intervention (often used in combination): *intelligent infobots, knowbots, chatbots, shopbots that help consumers find the best prices, and many others*. The most popular bots that can be found on the Internet are programs known as spiders or crawler that are used for searching. They access Web sites to retrieve documents and follow all the hypertext links in them. Catalogs accessible by search engines are then generated. The largest use of bots is in Web spidering, in which an automated script fetches, analyzes, and files information from Web servers at many times the speed of a human. Each server can have a file called robots.txt, containing rules for the spidering of that server that the bot is supposed to obey.

8.5.3 Virtual Pink Dolphins

In this project, virtual pink dolphins are bots to be designed for autistic learning. Virtual pink dolphins are designed with three major functions to communicate, to perform, and to learn (Fig. 8.6). These bots are 3D modeled following the real pink dolphins at the Underwater World Singapore. They are animated following their natural behaviors in the dolphin lagoon at the Underwater World Singapore.

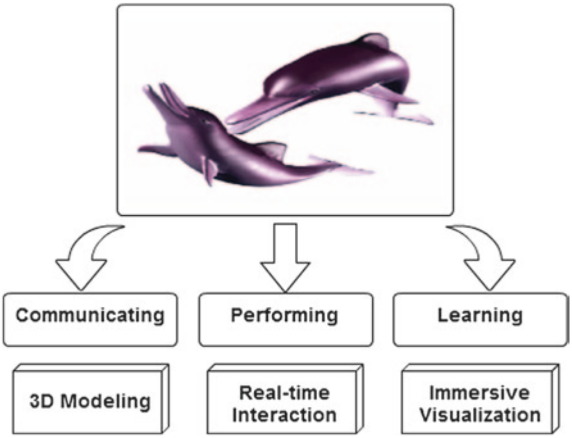

Fig. 8.6 Virtual pink dolphins

The virtual pink dolphins are able to understand human gestures, and to perform following the instruction of the trainers.

8.5.4 An Immersive and Interactive Environment

The Institute for Media Innovation has an immersive room (Fig. 8.7), which is equipped with latest immersive graphics hardware and software. The immersive room has a spherical 3D screen spanned 320°. The screen is for displaying images

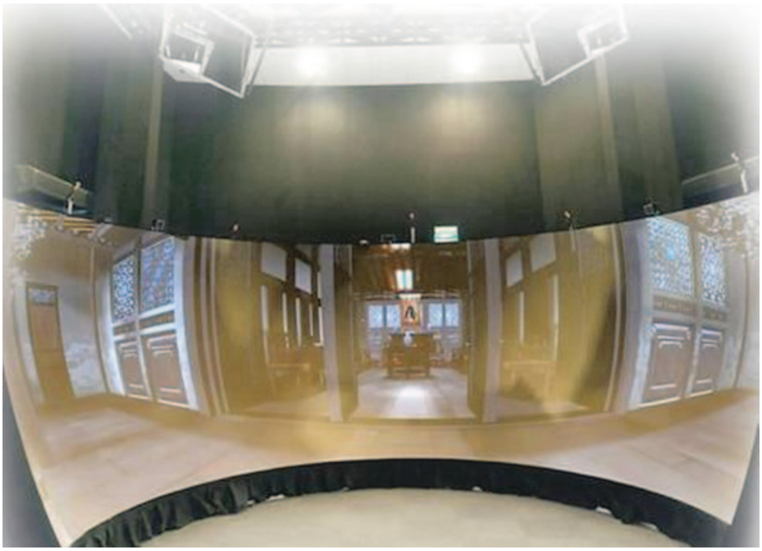

Fig. 8.7 The immersive and interactive environment

from five projectors which are ceiling mounted. Each of the projectors produces a pair of images that swap at a high speed. The five pairs of projected images are synchronized to form a seamless view for stereographic visualization. Five graphics workstations are linked together in a local area network to provide high-performance graphic capability. Electromagnetic 6DOF tracking is implemented in the Immersive Room to monitor the viewers' position and orientation. Microsoft Kinect technology is used in the Immersive Room for human motion tracking and gesture detection.

8.5.5 Virtual Pink Dolphins Based Games

A learning game is designed to teach children with ASD basic concepts or skills. They can follow the visual instructions to control the virtual dolphins with certain gestures. Rewards will be given as a form of virtual dolphins performing certain antics (e.g., leaping from the water to somersault in the air) and collecting stars if learners with ASD give correct response. Three difficulty levels are designed to allow learners with ASD making progresses (they are promoted to next level after successfully completed five actions correctly). Once all the three levels are done, a final score will be given based on the answers responded and time used by the learners. A tutorial is provided for beginners to learn the game and in-game feedbacks are also provided immediately after learners give their inputs. Figure 8.8 shows an autistic child is interacting with the virtual pink dolphins.

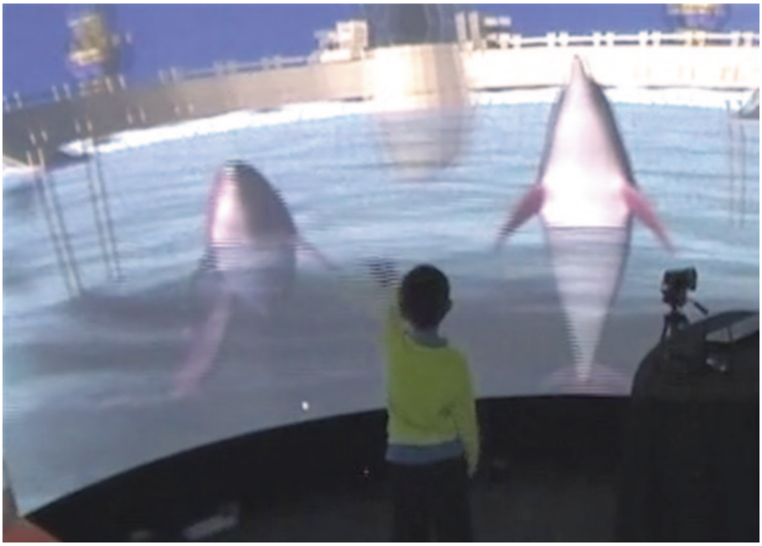

Fig. 8.8 Virtual pink dolphin based learning games

8.6 Conclusion

Autism is an especially difficult disorder to treat because of its triad of impairments (i.e., stereotyped behavior, communication, and social interaction), its co-morbid subtypes (e.g., Timothy's Syndrome and Rett's Syndrome) and varying degrees of severity that range from mild to profound. VR and other advanced technologies are improving the treatment for children with ASD. It helps to enhance the lives of these children by increasing the efficacy, efficiency, and availability of quality in special education as well as neuro-rehabilitative medicine. The Virtual Pink Dolphin Project has shown that VR can be utilized in many ways to improve the prognosis of children diagnosed with ASD as well as to develop a protocol for improving the quality of daily living for these children with ASD. One advantage of VR application noted in the Virtual Pink Dolphin Project is that it could be used to filter out stimuli to aid in establishing focused attention in children with ASD. The person (teacher or therapist) working with these children can adjust the level of stimuli in the VR learning environment (i.e., the virtual dolphinarium) according to each autistic child user, adding in more distractions as the child's performance improves. For future research, the Institute for Media Innovation is particularly interested in exploring and expanding the use of the LAS of technogogy to create an enhanced VR-based treatment that teaches communicative and social interactive skills as well as daily living activities to children with ASD.

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Afterword

During my visit to Nanyang Technological University in Singapore in 2011, I had a chance to meet Professor Y. Cai. He shared with me several of his interesting projects which were undergoing in schools in Singapore. I was excited by the FutureSchools@Singapore program initiated by Singapore Ministry of Education (MOE) and Infocomm Development Authority of Singapore (IDA). It is interesting to learn that schools in Singapore are embracing 3D technology for classroom teaching and learning.

This book, *3D Immersive and Interactive Learning in Singapore* edited by Professor Cai, is an outcome of the above projects. It reports applications of 3D immersive and interactive technologies (3D I^2T) such as virtual-reality in education. The various chapters address not only the technical aspects of 3D I^2T, but also pedagogy, curriculum, evaluation, and classroom integration; together they present a comprehensive research and development effort involving 3D I^2T in education. This book contributes to the field of educational technology in a number of ways. First, it demonstrates the feasibility and potential of applying 3D I^2T into a wide variety of K-12 subjects including Mathematics, Sciences, and special education; second, it shows the necessity for people with different expertize such as technology, content disciplines, pedagogy to work together in order to develop high quality of curriculum materials; and third, it shows preliminary evidence on the effectiveness of 3D I^2T in education. The book is a solid contribution to both knowledge and practice.

Singapore is internationally known for its excellent student performances in various subjects, particularly in Mathematics and Science, based on some major international comparison studies such as Trend in International Math and Science (TIMSS) and Program for International Student Assessments (PISA). The technology innovations in K-12 teaching and learning as exemplified in this book demonstrate one aspect of the Singapore education system that enables the excellence in student learning. Standards-based education reforms are an international phenomenon, particularly in the USA, and investment in resources, particularly technology, is a major part of the above reforms. This book, 3D *Immersive and*

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Interactive Learning in Singapore, will inspire people in other countries to explore and expand the frontier of integrating promising learning technologies for improving student learning.

Research in educational technology has established that a key to the success of an educational technological innovation is the integration of technology into the system. Technology alone can not bring about desirable learning outcomes in students; it is the system change resulting from technology integration that makes a difference. This book, *3D Immersive and Interactive Learning in Singapore*, presents some exemplary cases on how a systematic change by integrating 3D I^2T may take place. It should be a valuable resource for all people who are interested in integrating technology to improve student learning, such as computer scientists, media experts, content experts in Mathematics, Science, Engineering, and others, school teachers, pedagogy experts, school administrators, psychometricians, and so on.

I congratulate Professor Cai for this timely contribution to both scholarship and practice in applications of education technology in K-12 education!

Professor Xiufeng Liu
Graduate School of Education,
University at Buffalo, The State University of New York, USA

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