北京师范大学智慧学习研究院
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# VSE Primer: Concept, Technology, Architecture and Implementation of Virtual and Simulation Experiment

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# VSE Primer: Concept, Technology, Architecture and Implementation of Virtual and Simulation Experiment

BNU SLI

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# Chapter 1 Elaboration of Virtual and Simulation Experiment

## 1.1 Introduction to Computer Simulation

Computer simulation is based on mathematical models, which are designed to predict the behavior or outcome of a real-world or physical system. Since they allow to check the reliability of chosen mathematical models, computer simulations have become the useful tools for the mathematical modeling of many natural systems in physics, chemistry, climatology, biology and manufacturing, as well as human systems in economics, psychology, social science and so on. Simulation of a system is represented as the running of the system's model. It can be used to gain new insights into new technology and to estimate the performance of complex systems.[1]

### 1.1.1 Evolution of Computer Simulation

Computer simulation developed hand-in-hand with the rapid growth of the computer, following its first large-scale deployment during the Manhattan Project in World War II to model the process of nuclear detonation. It was a simulation of 12 hard spheres using a Monte Carlo algorithm. Computer simulation is often used as an adjunct to, or substitute for, modeling systems for which simple closed form analytic solutions are not possible. There are many types of computer simulations and their common feature is the attempt to generate a sample of representative scenarios for a model in which a complete enumeration of all possible states of the model would be prohibitive or impossible.

Computer simulations could be found in virtually any field of knowledge production today.

Arguably, the best known methods are that of "Monte Carlo" and "agent-based" simulations. A typical Monte Carlo simulation uses random numbers to provide a stochastic model of a physical phenomenon.

### 1.1.2 Simulation and Computer Technology

Simulation technology is a simulation model technology that uses simulation hardware and simulation software to reflect system behavior or process through numerical experiments through simulation experiments. Simulation technology includes computer graphics, image processing and programming algorithms.

#### Computer Graphics Technology

Computer graphics technology plays an important role in computer simulation technology. Computer graphics, as the branch of computer science, deals with generating images with the aid of computers. Today, computer graph-

1 https://en.wikipedia.org/wiki/Computer_simulation/

ics is a core technology in digital film, video games, cell phone and computer displays. With the displays of most devices being driven by computer graphics hardware, people have developed a great deal of specialized hardware and software. The phrase “Computer Graphics” was coined in 1960 by Verne Hudson and William Fetter of Boeing. It is often abbreviated as CG, or typically in the context of film as CGI. Some topics in computer graphics include user interface design, sprite graphics, ray tracing, geometry processing, computer animation, vector graphics, 3D modeling, GPUdesign, implicit surface visualization, computational photography, scientific visualization, computational geometry and so on. The overall methodology depends heavily on the underlying sciences of geometry, optics, physics, and perception.[1]

#### Image Processing Technology

Image processing is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful feature information from it. It is a type of signal processing in which the input is an image and the output may be an image or characteristics and features associated with the image. Nowadays, image processing has become one of the rapidly growing technologies. It also constitutes core research area within engineering and computer science disciplines. Image processing basically includes the following three steps: importing the image via image acquisition tools, analysing and manipulating the image, output in which result can be altered image or report that is based on image analysis.

There are two types of methods used for image processing namely, analog and digital image processing. Analog image processing can be used for the hard copies like printouts and photographs. Image analysts use various fundamentals of interpretation while using these visual techniques. Digital image processing techniques help in manipulation of the digital images by using computers. At this time, The three general phases, which all types of data have to undergo, are pre-processing, enhancement, and display, information extraction. [2]

# 1.2 xR(AR/VR/MR) Technology and Its Applications

## 1.2.1 Classication and Terminology

#### Virtual Reality (VR)

Virtual reality (VR) is the term used to describe a three-dimensional, computer generated environment which can be explored and interacted by the person. That person becomes part of the virtual world or immerses himself into this environment, where he is able to manipulate objects or perform a series of operations to determine what happens.[3]

VR is a simulated experience that can be similar to or completely different from the real world. Applications of virtual reality can include entertain-ment and educational purposes. Other distinct types of VR style technology include augmented reality and mixed reality.

Standard virtual reality systems currently use either virtual reality headsets or multi-projected environments to

1 https://en.wikipedia.org/wiki/Computer_graphics

2 https://sisu.ut.ee/imageprocessing/book/1

3 https://virtualspeech.com/blog/how-virtual-reality-can-improve-online-learning

generate realistic images, sounds and other sensations, which simulate the physical presence of users in a virtual environment. A person, who use virtual reality equipment, is able to look around the artificial world, move in it and interact with virtual features or objects. The effect is commonly created by VR headsets consisting of a head-mounted display with a small screen in front of the eyes, but it can also be created through specially designed rooms with multiple large screens. Through virtual reality typically incorporates auditory and video feedback, it may also allow other types of sensory, such as force feedback through haptic technology.

### Augmented Reality (AR)

Augmented reality (AR) is an interactive experience of a real-world environment where the objects are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, olfactory.

AR can be defined as a system that fulfills three basic features, including a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects. The overlaid sensory information can be constructive (i.e. additive to the natural environment), or destructive (i.e. masking of the natural environment).

This experience is seamlessly interwoven with the physical world, so it is is seen as an immersive aspect of the real environment. In this way, AR alters one's ongoing perception of a real-world environment, whereas VR completely replaces the user's real-world environment with a simulated one. AR is related to two largely synonymous terms: mixed reality and computer-mediated reality. [1]

### Mixed Reality (MR)

Mixed reality (MR) is the merging of real and virtual worlds to generate new environments and visualizations, where physical and digital objects coexist and interact in real time. Mixed reality does not only happen in the physical world or virtual world, but also a hybrid of reality and virtual reality. Through immersive technology, it encompasses both augmented reality and augmented virtuality.[2]

Knowing what is VR is not the full picture of the tech world today. Virtual and augmented realities are very similar and often the boundary between them is not clear. AR appends the real environment with a simulated one, overlaid on top. Augmented reality uses algorithms and sensors to detect the location of the camera, and then superimposes 3D graphics/objects into the human visual field via smartphones/glasses/projections.

One way to describe the difference between VR and AR is to compare scuba diving and visiting the aquarium. Virtual reality would be like swimming in the sea along with fish, while in augmented reality you'd see a fish popping out of a pocket or a hand. On the other hand, unlike VR, AR provides users with more freedom of action and does not require a headmounted display.

The term "mixed reality" is often mistaken for augmented reality. But actually, MR (or hybrid reality) is a more sophisticated kind of technology, where AR is a subcategory of it. It includes non-commercial applications like military simulation-based learning programs, virtualization environments for manufacturing, healthcare, aviation, etc.[3]

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1 https://en.wikipedia.org/wiki/Augmented_reality

2 https://en.wikipedia.org/wiki/Mixed_reality

3 https://thinkmobiles.com/blog/what-is-vr/

## 1.2.2 Virtual Reality Features and Technology

Virtual reality (VR), which uses computer modeling and simulation, enables a person to interact with an artificial three-dimensional (3D) multi-sensory environment. VR applications immerse the user in a computer-generated environment, simulating reality by using interactive devices that send and receive information and are worn as goggles, headsets, gloves, or body suits. In a typical VR format, a user wears a helmet with a stereoscopic screen to watch animated images of a simulated environment. The illusion of "being there" is affected by motion sensors that receive the user's movements and adjust the view on the screen in real time. Therefore, a user could tour a simulated suite of rooms, and experience changing viewpoints and perspectives which are related to the turnings and steps of his own head. Wearing data gloves equipped with force-feedback devices, the user can even peceive and manipulate objects that he sees in the virtual environment.[1]

Virtual reality usually has 3I characteristics:

**Immersion:** One feature of VR is its physical level of immersion, defined by the degree a user associates being within a virtual environment (Rebeloet al., 2012; Parsons, 2015). Immersion is reduced when a user is able to perceive aspects of the real world while experiencing the virtual world. For example, users who can perceive the frame of a projection screen, depicting a virtual environment that simulates being in outer space, may compro-mise the users' level of immersion. When classifying the level of immersion, based on the human-machine interface, there are three types: full immersion is achievable when the user utilizes a HMD (goggles, VR helmet or headset); semi-immersion is achievable when the user utilizes large projection or liquid crystal display (LCD) screens; and non-immersion is achievable when utilizing typical desktop computer setups with keyboards and mice (Gutiérrez Alonso et al., 2008; Rebelo et al., 2012; Parsons, 2015). Note that the main difference between these levels of immersion is due to the user's field of vision (FOV), where an optimal FOV of 180 degrees horizontal and 60 or more degrees vertical is achievable with the HMD hardware (Rebelo et al., 2012). Reduced perception (seeing, hearing, touching) of the real world tends to result in greater levels of VR immersion (Gutiérrez Alonso et al., 2008; Rebelo et al., 2012).[2]

**Interaction:** Interaction is a means of communicating with the system. In contrast to the traditional human-computer interaction which uses 1-2 dimensional (1D, 2D) means, like mouse, keyboard or keypad, interaction in VR is usually carried out in 3 dimensional (3D) ways, such as space ball and head-mounted device (HMD). Some features for interaction in VR systems are effectiveness, real-time reaction and human participation. In a computer-generated virtual environment, people can interact with some sensing devices, feeling as if they are in the real world. In terms of interactive functionality, VR is responsive to user input – gestures, verbal commands, head movement tracking etc. Why does it matter for businesses? For example, every product in a virtual clothing store can be interacted and manipulated with using either controllers or by gazing at certain points. In that way, the experience has gone from passive observation (looking at photos of products on a website) to active participation (being in the first row of a fashion show). In addition, customer interaction in the virtual world can be tracked and used as a tool to understand customer needs and influencethe purchase decision-making process.

**Imagination:** Imagination can be seen as the thought of the system designer to achieve a particular goal. With the applicability of the VR system for complex problem solving in diverse fields, it is a more efficient and effective means of expressing ideas than the traditional 2D drawing or text explanation. Virtual environment enables users to immerse themselves and acquire new knowledge, enhance emotional and rational understanding, so that us-

1 https://www.britannica.com/technology/virtual-reality

2 https://www.frontiersin.org/articles/10.3389/feduc.2019.00080/full

ers deepen concepts and sprout new associations. It can be said that virtual reality can stimulate people's creative thinking.

Burdea and Coiffet raised the 3I of virtual reality–immersion, imagination, and interaction, as shown in the following figure 1.1(1).

Virtual Reality (VR) is an integrated technique involved computer graphics, human-computer interaction and artificial intelligence etc.

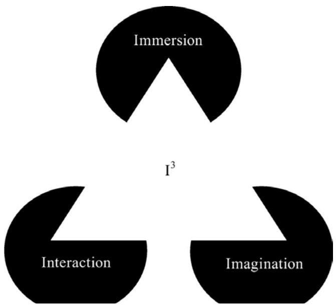


Figure 1.1: Characteristics of VR

## 1.2.3 Virtual Simulations Concept

Virtual simulations represent a specific category of simulation that utilizes simulation equipment to create a simulated world for the user. [1]

Virtual simulations allow users to interact with a virtual world. Virtual worlds operate on platforms of integrated software and hardware components. In this manner, the system can accept input from the user (e.g., body tracking, voice/sound recognition, physical controllers) and produce output to the user (e.g., visual display, aural display, haptic display) .Virtual Simulations use the aforementioned modes of interaction to produce a sense of immersion for the user.[2]

## 1.2.4 Virtual Reality Applied in Education

### Virtual Reality

Virtual reality could be used to improve student's learning and engagement. VR education can change the delivery method of educational content. It works on the premise of creating a virtual world where users can not only see it but also interact with it. Being immersed in what you're learning motivates you to fully understand it. It'll require less cognitive load to process the information.

Here are some obvious benefits that VR brings about.

1. Better sense of place: Because of the feeling of presence provided by VR, students can learn about a subject by living it. This feeling engages the mind in an extraordinary way.

1 https://www.marxentlabs.com/what-is-virtual-reality/

2 https://en.wikipedia.org/wiki/Simulation#Computer_simulation

2. Learn by doing: With VR education, learners are inspired to discover themselves. Students have an opportunity to learn by doing instead of passively reading.

3. Emotional reaction: VR in education makes students easily participate in the whole time, making the experience unforgettable.

4. Visual learning: Many people are visual learners — VR is really helpful for such learners. Instead of reading about things, students actually see the things they're learning about. It makes them easier to understand that the ability to visualize complex functions or mechanisms.

VR creates infinite possibilities that people can experience. Here are some of the experiences you can create with VR.

1. Virtual fields trips: VR technology can be used to enable students to participate in topics related to geography, history, or literature by providing a deeply immersive senses of place and time. Simply imagine geography lessons where you can visit any place on the earth. The experience is much more richer than just reading about it.

2. High-tech training: VR is a good solution for highly technical training fields like the military or the medical industry. For example, the most important challenge for medical students learning anatomy is to understand the three-dimensional structure of human body and how different systems fit together. VR education can help solve this problem.

3. Internships: Another benefit of using virtual reality in education is that it help to expand students' exposure to careers. It improves people's ability to imagine themselves from the perspective of others. Career expeditions show what it's like to work in a field — students can explore a day in someone's career, see what person is studying, and understand what a person likes — or doesn't like — about their job. As a result, the experience becomes familiar to students.

4. Group learning: VR education gives the opportunity to socialize learning experiences by allowing students to communicate with each other. Using avatars and mapped facial expressions, people can get together to discuss, synthesize, and learn from each other. [1]

5. Distance learning: VR allows us to bridge the gap between educators and learners. With VR, distance learning tools can put educators and students in the same room with digital representations of themselves — teachers can transmit to the VR world and guide students through their experiences.

### Augmented Reality

The educational value of AR is closely related to the way in which it is designed, implemented, and integrated into formal and informal learning environments. [2]An important consideration is how AR technologies support and provide meaningful learning. It will be fruitful for educators to consider AR as a concept rather than a certain type of technology. The involvement of educators is important to promote the development of favourable AR applications for teaching, which increases the potential for AR to be incorporated in education. AR applications have been de-

1 https://xd.adobe.com/ideas/principles/emerging-technology/virtual-reality-will-change-learn-teach/

2 https://eu-acerforeducation.acer.com/innovative-technologies/mixed-reality-in-education-boosting-students-learning-experience/

veloped for many educational areas. [1]

The importance of augmented reality education can be summed up in the following :

1. Gain knowledge about how to use computer and portable devices.
2. Increase teacher efficiency in education.
3. Motivate students to participate in the lesson.
4. Add a new dimension to teaching concepts compared to other teachingmethods.
5. Increase educational effectiveness in cooperative and experiential learning processes.
6. The teacher will acquire the knowledge and skills to use this technology.
7. To bridge the gap between theoretical and applied education, we should focus on how to combine the real with virtual world in order to achieve the various goals and requirements of e-learning.
8. Students who are absent from classes can continue their lessons at home without the presence of the teacher.

### Mixed Reality

Mixed reality is the fully immersive experience that requires students to wear an HMD (head mounted display) and a motion controller, through which they can interact with an environment produced by the mixture of real and virtual worlds, where physical and digital objects co-exist. Thanks to this Mixed Reality, students can touch and manipulate objects to gain deeper understanding of them. Students can also interact with data sets, complex formulas and abstract concepts, which could be more difficult to understand through teacher's verbal instructions. For many students, in fact, learning by doing is easier than learning by listening. This second kind of mixed reality provides a more engaging, interesting and effective learning experience than the first, needless to say, it is more than all other traditional educational methods(2).

Due to its characteristics, mixed reality gives professional educators new innovative possibilities to explore with learners : [2]

1. Engaging: direct experience generates an effective way to captivate those students who struggle, or it can just provide another opportunity to boost the engagement during lessons at school.
2. Universal: regardless of social, economic or geographic disparities, MR at school brings together people and encourage interaction between people.
3. All-purpose: as said before, Mixed reality could be used to teach any topic because it is easier to see and hear something, rather than let it explain, especially abstract concepts.
4. Faraway worlds: using MR devices, students and teachers could go back to the past, interacting with objects, animals or human beings that are no longer existing: dinosaurs and primitives get a new, more realistic image in learners' minds.
5. No geographical limitations: it is not always simple to plan the perfect school trip. Student safety, as well as school budget, often affects the range of choices when deciding where to go. Thanks to MR, there are no more restrictions in this class.

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1 https://www.hindawi.com/journals/ahci/2019/7208494/#B4

2 https://acerforeducation.acer.com/innovative-technologies/mixed-reality-in-education-boosting-students-learning-experience/

# 1.3 Knowledge about Simulation Modeling

## 1.3.1 Definition for the Simulation Modeling

Simulation modeling is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world. Simulation modeling is used to help designers and engineers understand whether, under what conditions, and in which ways a part could fail and what loads it can withstand. Simulation modeling can also help to predict fluid flow and heat transfer patterns. The simulation software is used to analyze the approximate working condition.[1]

## 1.3.2 Simulation Modeling Technologies

### 1. Computer simulation modeling technology

Computer simulation modeling is a discipline gaining popularity in both government and industry. Computer simulation modeling can assist in the design, creation, and evaluation of complex systems. Designers, program managers, analysts, and engineers use computer simulation modeling to understand and evaluate 'what if' scenarios. It can model a real or proposed system by using computer software and is useful when changes to the actual system are difficult to implement, involve high costs, or are impractical. Some examples of computer simulation modeling familiar to most of us include: weather forecasting, flight simulators used for training pilots, and car crash modeling.[2]

### 2. Mechanism simulation technology

Mechanism simulation relates to the simulation of physical systems, through which movement, degree of freedoms, velocities and component stresses can be simulated and analyzed for whole machine optimization.

### 3. Process and system simulation technology

Process and system simulation involves the simulation of different organizations and operational systems, including but not limited to manufacturing systems, industrial production processes, business service systems, complex problem-solving process, business organizations, human systems, and auto-motive assembly systems.

### 4. Agent-based simulation technology

Agent-based simulation is a rapidly developing modeling and simulation method that can be used to model and simulate industrial processes and complex scientific systems. Agent-based simulation builds up its models using a bottom-up architecture. It consists of a series of autonomous agents, which operate and interact with each other complying with defined simulation specifications in a simulation world.

### 5. Discrete-event simulation technology

Discrete-event simulation is a more mature simulation method than agent-based simulation. Discrete-event simulation is a way to build up models in a top-down architecture and observe time-based behaviors within a system. Formal methods have been developed to construct discrete event simulation models and ensure that the models are credible.[3]

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1 https://en.wikipedia.org/wiki/Simulation_modeling

2 https://www.ors.od.nih.gov/OD/OQM/cms/Pages/default.aspx

3 https://www.researchgate.net/publication/332962311_Introduction_to_Modeling_and_Simulation_Techniques

# 1.4 Virtual Online Learning and Experiential Learning

In a traditional classroom or lecture, you learn by listening to teacher and talking to classmates. There classes usually have a specific time and locations. However, with online learning, you can still receive the same high quality teaching anywhere in the world and as someone who is there in person.

Online learning is typically conducted over the internet, as a series of courses you can access anytime and anywhere. Socializing and questioning are done through discussion forums or via email.

## 1.4.1 VR-based Online Learning

Online schools (virtual school or e-school or cyber-school) teach students entirely or primarily online or through the Internet. It has been defined as “education that uses one or more technologies to deliver instruction to students who are separated from the instructor and to support regular and substantive interaction between the students. Online education is available around the world for all levels of education (K-12, college, or graduate school). This type of learning enables the individuals to obtain transferable credits, take recognized examinations, or advance to the next level of education over the Internet.[1]

A virtual classroom is an online learning environment that allows teachers and students to communicate, interact, collaborate, and explain ideas.

A virtual classroom enables students to access high-quality teachers anywhere on the planet, as long as they have a reliable internet connection. This can break down most of the common barriers to synchronous learning: cost, distance and timing(3).

### What are the advantages?

#### 1. Scalable

When investing in the future of a business, it’s important to consider flexibility in mind. Where the business is now might not be where it is in five years time. The advantage of combining the learning management system with an integrated virtual classroom is that the courses can be expanded or reduced as needed.

#### 2. Accessible

A virtual classroom is accessible to anyone who has a computer, tablet or smart phone. It doesn’t matter about where each potential student is based geographically, or even whether they are suffering from health or mobility issues. Everyone will be able to log in at that time they choose.

#### 3. Affordable

The costs building a learning management system and virtual classroom is very advantageous compared with the cost of expanding into additional physical classrooms. These savings can generally be passed onto students, which can increase the acceptance rate of the course.

1 https://en.wikipedia.org/wiki/Virtual_school

**4. Effective**

The tools and resources provided from a virtual classroom have proven to be effective. Presenting teaching materials in this way allows students to have greater control over how and when to access, which means they can take full control of their learning experience and increase their likelihood of success.

**5. Popular**

There's a lot to be said about an educational tool that students are keen to use. For all the reasons mentioned above, learning management systems with inbuilt virtual classrooms are popular with students. This popularity means that students are more likely to spend time studying and revising important course materials, and suggests that course drop out rates could be reduced(4).

**Disadvantages**

**Impersonal** There will always be people who will vastly prefer in-person learning to digital learning. Some tutors and students may be uncomfortable with the idea of delivering or engaging with a course that is taught entirely in a virtual classroom.

There are many ways to manage this. A learning management system will offer the opportunity for learners to communicate with their tutors and fellow students using video, audio and text chat mechanisms. Encouraging conversation via this forum can help to show that virtual doesn't necessarily mean lonely.

Virtual classrooms could also be used alongside in person classroom time to support and enhance learning opportunities.

**Extra training** Most virtual classrooms are designed to be used intuitively. Most students and staff are likely to be extremely comfortable using tech of this kind. However, some staff and students won't be as confident using digital tools and may need additional support to get started. It may be necessary to have a dedicated member of I.T. support staff available to fulfil this role.

Though there are a few disadvantages of incorporating a virtual classroom into a training school environment, we believe they are vastly outweighed by the many advantages.

A good learning management system can easily provide a virtual classroom space and online access to your course materials.

## 1.4.2 Virtual Reality Technology for Experiential Learning

Experiential learning is the application of theory and academic content to real- world experiences, either within the classroom, within the community, or within the workplace, which advances program or course-based learning outcomes that are specifically focused on employability skills. Experiential learning requires the student to not only engage in the experience activity, but also requires them to reflect upon their learning and how their skills learned through their academic studies can be applied beyond the classroom. Workplace experiences such as co-op and internships placements are only one form of experiential learning opportunities that can be provided to students. Such opportunities are typically divided into three categories – course focused, community focused, and work focused – giving students hands-on experiences not only in the classroom, but also in the community and the workplace (Strategic Transformation Group on Employability, Carleton University).

Here are some of the benefits of experiential learning with VR:

### 1. Accelerates learning

Repetitive learning or learning by rote can be dramatically improved by actually performing or visualising the learning material. VR learning uses problem solving, powerful visualisation, decision making and other elements to enhance the learning experience.

### 2. Safe learning environment

It is only natural that mistakes happen during the course of learning, and using VR simulations lets people learn in a safe controlled environment. Students can therefore try different approaches and understand for themselves what works best.

### 3. Bridges the gap between theory and practice

Students often learn textbook theory about a certain topic, experiencing this theory in an interactive 3D environment gives students a more memorable learning experience.

### 4. Increases engagement levels

The virtual world lets students collaborate and learn from each other, increasing overall engagement with a tangible outcome result.

### 5. Making complex learning easier

VR can simulate a range of complex topics, from brain surgery to gravity, bringing the learning process to life(5).

## 1.5 Smart Learning Environment (SLE)

Smart learning environment(6) is an adaptive system that puts the learner at the forefront, where it improves learning experiences for the learner based on learning traits, preferences and progress; features increased degrees of engagement, knowledge access, feedback and guidance; and uses rich-media with a seamless access to pertinent information, real-life and on-the-go mentoring, with high use of AI, neural networks and smart-technologies to continuously enhance the learning environment.[1]

Smart learning environments are IoT-based learning solutions, which are seamlessly integrated into our working and learning environment. Smart learning environments are therefore physical environments enriched with context-aware digital devices to improve and accelerate learning. Based on that, they can recommend the right learning content in the right place and at the right time. That's especially useful for life-long workplace learning. In short, we need artificial intelligence and the IoT, which is defined as a bundle of technologies that connects different types of IT ranging from RFID to data analytics and virtual reality. Smart learning environments at a very high level

1 https://www.mtu.edu/materials/k12/experiments/

of maturity require a powerful recommendation system. In this case, you need lots of data on the learning history of each user if you want to provide learning analytics.

With virtual reality applications, learners can be transported to distant places and environments or eras that were previously inaccessible. Augmented reality tools enable pupils to plan their school yards. An immersive space makes it possible to bring targets and learning environments, which would otherwise be inaccessible, close to learners. Smart learning environments are enabling teachers to plan and implement much more versatile learning modules than before. Learners in Helsinki have access to plenty of technologies, both free and licensed digital materials, and various physical and virtual learning facilities that can support their learning. Smart learning environments are already used in early childhood education and care, continuing throughout the learning path.

## 1.5.1 Definition of the Smart Learning Environment

The emerging field of smart learning environments, which can be online or physical, learning environments, is being defined and conceptualized by the members of the International Association of Smart Learning Environments (IASLE). Gwo-Jen Hwang, Distinguished Professor and Chair, National Taiwan University of Science and Technology, Taiwan, and the President, Executive the Board of IASLE, defined smart learning environments as, "technology-supported learning environments that make adaptations and provide appropriate support (e.g., guidance, feedback, hints or tools) in the right place at the right time based on individual learners' needs, which might be determined via analyzing their learning behaviors, performance and the online and real world contexts in which they are situated" (Hwang, 2014, p.5). IASLE's mission is, in part, to be "a cutting-edge professional forum for researchers, academics, practitioners, and industry professionals interested and/or engaged in the reform of the ways of teaching and learning through advancing current learning environments towards smart learning environments" (International Association of Smart Learning Environments, 2014). IASLE. Smart Learning Environments, a SpringerOpen Journal is associated with IASLE. This entry will include a brief introduction to the background of smart learning environments, preliminary definitions, descriptions, criteria, and a proposed framework for smart learning environments.

## 1.5.2 SLE Equipped with the Virtual Laboratory

The university's computer laboratory is currently one of the most challenging aspects when imparting practical tasks with regards to the education technology (ET) enhancement. In a virtual laboratory, students interacted with the GUI of the cognitive virtual laboratory environment and performed the practical task according to the given scenario. The event-driven schemas detected on the interface by the sensory memory via manipulation of a keyboard, a mouse and file manipulation events. This module has connected with perception and actuators. It presents the conception of an Intelligent Virtual Laboratory (IVL) based on PACA. This IVL provides the level of excellence of laboratory needs by enhancing the education technology for all computer education levels. This IVL offers smart learning environments, which students can efficiently perform practical course tasks online at home or anywhere. The proposed research described that intelligent laboratory companion (ILC) agents based on PACA which can be used as a laboratory assistant that has the ability of self-regulating learning to assist students in practical tasks of computer skill. It discusses the allegations of findings for online laboratory needs and practice practical courses learning. The Intelligent Electronic Laboratory (IE-Laboratory) system has been designed according to the learner/student requirements of training/practical work(7).

Laboratory experience is a key factor in technical and scientific education, but traditional laboratories are costly to maintain, limiting possibilities for practical exercises. Virtual laboratories have been proposed to reduce cost and simplify maintenance of lab facilities, while offering students a safe environment to build up experience and enthusiasm for STEM (Science, Technologies, Engineering and Maths) subjects without geographical limitations. Virtual labs enable students to participate and interact in inquiry-based classes where they can implement and analyze their own experiments, learn by using virtual objects and apparatus. Utilizing virtual labs provide students with the chance to develop critical thinking, innovative and team working skills, all of which are highly valued in today's job market. Numerous virtual labs have been developed by different organizations and large-scale international projects, and many of these are available as open source software. Virtual labs ease the pressure brought on universities and schools by cost and maintenance of real labs, while utilizing the extensive technological knowledge of students today. At their best, properly planned and executed virtual labs have been found to increase students' knowledge, skills and performance in examinations, while reducing limitations by geography, health and safety, cost and availability. In an online lab, investigation material, physical or virtual, is manipulated, and the effects of this anipulation are observed in order to gain insight into the relationship between variables in the conceptual model underlying the online lab.

Virtual labs offer a solution to the limitations of traditional practical classes in STEM education, by offering environments for students to interact with each other and use virtual objects and apparatus, through software interface which is connected to a hardware in one centralized place. Since elementary education reforms have emphasized inquiry-based learning, using virtual labs allow students to develop their reasoning, critical thinking, innovative and creative skills without the usual limitations of time, resources and space. They also enable inquiry-based learning while assisting in the acquisition of deep conceptual domain knowledge and inquiry skills. Virtual labs allow resources to be shared between geographically distributed educational institutions and users. Virtual labs are easy to set up, use and maintain, with notable reductions in cost and time. Hardware labs on the other hand are difficult to set up and very time-consuming and costly for the institutions to manage, and require a lot of technical expertise to run. In addition to being cheaper than hardware labs, virtual labs have the potential to be used in experiments that would be too dangerous or impossible to carry out in real life, e.g. practicing surgeries or testing the functions of a nuclear reactor: these labs allow students to learn from mistakes without causing any real damage to themselves or others. Experiments can also be repeated multiple times, providing students with the chance to change the parameters of their experiment. With regards to ethical education, the general view has largely changed in the past two decades, for example dissection labs becoming increasingly rare. Virtual labs are a way to bypass these types of ethically questionable practices while teaching students about anatomy, physiology and biology. Similarly, medical students can practice surgeries with no risk to the virtual patient.

# 1.6 Virtual and Simulation Experiment in Education

## 1.6.1 Definitions for the Virtual and Simulation Experiment

Virtual and simulation experiment will fully use virtual reality and simulation technology as the core technology, combine virtual reality technology with the application of key majors in schools, use virtual to replace complex objects, and replace the original ancient experimental operation methods; The high-cost experimental operation training class allows students to complete it easily and safely.

Virtual experiment refers to the use of multimedia, simulation, virtual reality and other technologies to create relevant hardware and software operating environments that can assist, partially replace, or even replace all aspects of the traditional experiment on the computer. The experimenter can complete each experiment as in a real environment. This kind of experimental project, the experimental effect obtained is equivalent to or even better than the effect obtained in the real environment.

The virtual experiment is based on a virtual experiment environment, and the emphasis is on the interactivity of the experiment operation and the simulation of the experiment results. Virtual experiment experiments are called electronic experiments, and dynamic experience. The effect of virtual experiments is to be able to combine with reality. Through experiments, we can determine whether we want to complete the current experimental phenomenon in our lives.

Structure of virtual and simulation experiment illustrated as the following figure 1.2.

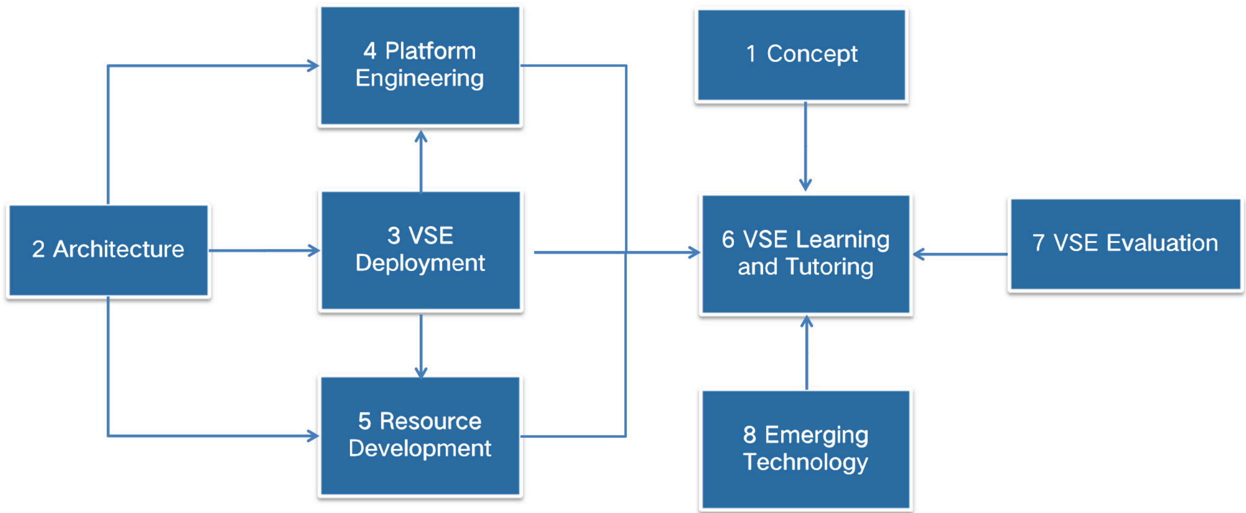


Figure 1.2: Structure of VSE Primer

VSE primer consists mainly eight chapters: concept, architecture, VSE deployment, platform engineering, resource development, VSE learning and tutoring, VSE evaluation, and emerging technology.

With the core of VSE, chapter 2 describes the concept and components of the virtual and simulation laboratory. Chapter 3, chapter 4 and chapter 5 introduce the deployment of virtual and simulation laboratory, platform of engineering, and the resource development. Chapter 6 introduces tutoring with VSE. Chapter 7 reviews the project evaluation of VSE. Chapter 8 will show the latest technology for virtual and simulation lab.

### 1.6.2 Classification of Virtual and Simulation Experiment

#### Virtual Interactive Simulation

Visual Interactive Simulation (VIS) is the development and application of simulations which produce a dynamic display of the system model and allow the user to interact with the running simulation environment. The reality interactive technology contributes to add some real interactive teaching concepts and phenomena in science, and the creation of an interactive learning environment for active safe mimic reality, so interactive simulations in teaching science is a fundamental element for the development of understanding of the learners to the concepts of scientific facts more attractive and suspense of the learner methods, known researcher simulation interactive in this paper as “learning environments and teaching used to give scientific concepts to students through testing materials science laboratories electronic mimic real laboratory interactive, and provides the same circumstances, but it is less expensive and more safety and accuracy in achieving results(8).”

### Virtual Experiment

Virtual experiments allow students to conduct experiments using a computer or a mobile device. Virtual experiments give students multiple attempts, before moving onto a hardware lab at a further stage of their studies, if they choose to pursue a certain subject. These virtual experiments are optimized for high school students, but anyone can learn the basics of materials science and engineering. They simulate basic materials experiments used by scientists and engineers. A scientific format, which presents the experimental conditions, procedure, data, and conclusions, is adopted for each virtual experiment. The goal is to illuminate the issues and important areas of concern within the field of materials.[1]

1 https://www.reading.ac.uk/virtualexperiments/experiments.html

# Chapter 2 Architecture for Virtual and Simulation Laboratory

The chapter describes the concept(9) and components of the virtual and simulation laboratory,its technology architecture, which divided into three layers, the infrastructure architecture, middleware layer, and application layer.

## 2.1 Virtual and Simulation Laboratory

### 2.1.1 Definition for the Virtual and Simulation Laboratory

A virtual laboratory can be defined as an environment in which experiments are conducted or controlled partly or wholly through computer operation, simulation, and or animation either locally or remotely via the internet. With regard to the computer animation type of virtual laboratory, the experiment is often a graphical model of the actual experiment.[1]

The virtual laboratory does not include physical hardware, but it allows the user to observe the process and the end product by way of animation.

Virtual laboratory is an open networked virtual experiment teaching system based on Web3d technology and virtual reality platform. It is the digitization and virtualization of various existing teaching laboratories.

The virtual laboratory consists of a virtual laboratory bench, a virtual equipment library and an open laboratory management system. The virtual laboratory provides a brand-new teaching environment for setting up various virtual experiment courses. The virtual experiment table is similar to the real one, which can be used by students to configure, connect, adjust and use experimental equipment. Teachers use the equipment in the virtual equipment library to freely build any reasonable typical experiment or experimental case. This is an important feature of the virtual laboratory that is different from the general experimental teaching courseware.

Virtual labs are considered as one of the most important techniques of e-learning, as they enable both teachers and students to achieve the goal of educational process. This is to promote the application of the curriculum practice at any time and place, and without any form of restrictions.

As for the applications of technology in the field of education, there are many benefits that can be mentioned. The spread of these technological applications also faces many obstacles.

1 https://www.tandfonline.com/doi/full/10.11120/ened.2009.04020070

## 2.1.2 Benefits and Constraints

Benefits and constraints[1] of using virtual labs in the educational process.

### Benefits

Nine benefits of using virtual labs:

1. Virtual labs motivate students to conduct laboratory experiments.
2. They satisfy the scientific enthusiasm of students, enabling them to easily access the various experiments regardless of time or place.
3. Increase the understanding of scientific courses in physics, chemistry and biology, and improve student performance.
4. Eliminate boredom because it provides fun during the experiments.
5. The virtual labs will increase the rate of scientific research because it saves time and energy and enables researchers to use their time more effectively.
6. The virtual labs will enable students to use modern technology and enable them to track the tremendous progress of the information revolution.
7. Students will be able to use the scientific method to solve problems.
8. Develop teaching and learning methods to improve the effectiveness of the educational process.
9. Increase the communication between students and others on the Internet, which helps to exchange ideas and experiences.

### Constraints

Three impediments to use virtual labs:

1. They require high-standard computer devices in order to simulate the precise phenomena with full details and create a three-dimensional virtual lab.
2. They require professional programmers with strong skills in different programming languages. They also require a team of experts in the scientific materials, teachers and experts in psychology.
3. One of the negative effects of virtual labs is that it reduces the direct interaction between students and students, and between students and teachers, given that the communication between them is mostly electronically.

In addition, three points to consider in using virtual labs:

1. Virtual labs should not completely replace "real world labs", but instead enhance it. Virtual labs should not completely replace the real lab, because students may miss valuable practical experience that could be a value in future education. However, virtual labs can enhance these experiences. By performing a virtual lab on the material before a "real world" lab, it allows students to make mistakes without fear of not being able to com-

1 https://sites.google.com/site/virtuallabsadvantages/

plete the experiment correctly. Furthermore, virtual labs could present abstract ideas that may not normally be easily viewed. For example, when learning about gas laws, it may be hard to visualize what is actually occurring at the microscopic level, but the interactions can be made visible and tangible with use of a simulation.

2. Make sure that virtual labs are accessible to students. Virtual labs need to be accessible because they provide students with somethings they can not use in the classroom a chance to learn content in a meaningful way. This means making sure that students can have a way to access labs. If it is software based, we need to make sure students have a copy they can use. If all students do not have readily accessible computers, we need to determine times when and where they can access machines. Online labs, demos, and simulations increase this accessibility. Another feature of accessibility is the rigorous examination of the demo, simulation, or lab and determine if it is appropriate for the age group of learners. Some virtual labs can be quite in depth and they may be easy to use by the teacher, but they may be beyond the capability of students in the classroom.

3. Strictly assess virtual labs and their usefulness(1). Not all virtual labs are created equal, and some may not be appropriate for a particular classroom or be well designed. There is criticism that the virtual labs are merely a substitute for text or are overly cheesy. To address this, each virtual lab, demo or simulation needs to be fully evaluate to its usefulness. Each needs to be examined to make sure that it matches what is being taught, which will keep students interested and provides a form of interaction that could not usually be easily conducted in the classroom.

## 2.2 Components of the Virtual and Simulation Laboratory

Virtual and simulation laboratory system components illustrated as the following figure.

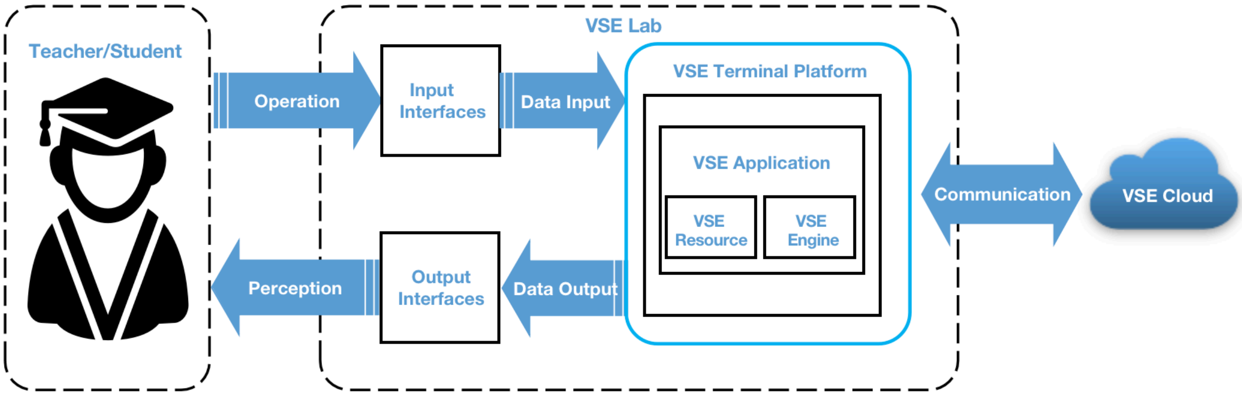


Figure 2.1: Data Flow Model of VSE Lab

It consists mainly three parts: human computer interfaces, terminal platform, and VSE cloud.

## 2.2.1 Terminals Applied in the Laboratory

### VR Head Mounted Display

A VR headset, also known as HMD (Head Mounted Display), could be seen as an enhanced display screen in front of the eyes. These virtual reality products and devices are typically connected to a PC, smartphone or other types of computing platforms. Consumer applications include gaming, watching movies and live events, social media interactions and virtual tourism. Enterprise and commercial applications include education and training, architecture, medicine, architecture where detailed rendering of objects and scenes of interest helps to create more efficient workflows and tasks through visualization. VR headsets embed sensors, one or more image sensors, connectivity and, of course, high-resolution displays with high frame rates and wide field-of-view to deliver a realistic images and immersive experiences.

Virtual reality company needs to provide a wide range of innovative products and ICs to enhance the design of VR headset. Key products include Bluetooth and NFC connectivity solutions, motion, environmental and proximity sensors, MEMS speakers and microphones, power management, and an array of microcontrollers. We also offer power management solutions including wireless charging, USB PD, signal conditioning and protection.

### HMD Key Parameters

**1. Motion to Photon Latency (M2P)**

M2P(10) describes the length of time between the user performing a motion and the display showing the corresponding content for that particular motion. For VR systems, the M2P is typically less than 20 milliseconds. For AR, the required latency is less than 5 milliseconds. This is due to the fact that the user has the surrounding environment as a reference.[1]

**2. Near Eye AR Displays (NED)**

Because the resolution and image source defects still affect the perception quality, the quality challenges of near eye AR displays are very different. The biggest challenge is to create a small form factor system with a large FOV and eyebox. In addition to image generation challenges, everything should be perfectly matched with the real world.The brightness of sunlight is 1.6 billion nits. The brightness of mobile phone is between 500 and 1,000 nits. A large eyebox generally means low transmission efficiency, which will set demands for light source and waveguide. These are just some of the challenges related to ambient light in eyewear design.

**3. Latency**

Latency is the term used for the time between input and output. For the layman, that means the time it takes for the picture in your VR world to catch up to your new head position each time. In order for VR technology to trick your brain into thinking that you are in an immersive world, it requires very low latency. An absolutely top-notch experience usually equals latency of 20ms or less; any more and we start to notice an unnatural lag.

**4. Pixels**

Pixels are the dots that make up a picture. The more pixels per square inch of the screen, the crisper the image

1 https://www.optofidelity.com/offering/solutions/ar-and-vr-hmd-testing/

would be.

**5. Display Technology**

The display is the most obvious part of the HMD, so it stands to reason that we would start here, in the visual center of the device. Today, an HMD might use one of several techniques to transfer images to brain, but the most common is the use of liquid crystals. Sounds painful, right? This is more commonly known as an LCD panel, and the same type of panel is used in smartphones, modern televisions and computer monitors. A newcomer to the display technology game is OLED (Organic Light-Emitting Diode), then we have begun to see more and more OLEDs.

**6. Refresh rate**

The refresh rate refers to the speed at which the display changes its contents in a specific period of time. Typically, modern LCD computer monitors can do this 60 times per second, or at 60Hz. This also corresponds to a maximum frame rate of 60 frames per second – or 60fps – where one frame equals a full image on your screen.

**7. Audio Hardware**

Normally, you can choose to use your own headphones in conjunction with your HMD. Some HMDs currently include their own optional headphones, while others do not. Positional, multi-speaker audio, giving you the illusion of a 3-dimensional world, is a technology that already exists (for example you may already use surround sound somewhere in your home), and it can slot in seamlessly with existing HMDs.

**8. Field of View (FoV)**

Field of view, or the extent of the observable environment at any given time, is one of the more important aspects of virtual reality. The wider the field of view, the more present the user is likely to experience.

**9. Degree of Freedom(DoF)**

Degrees of freedom (DoF) refer to the number of ways a rigid object can move through three dimensional space. There are six total degrees of freedom to describe every possible movement of an object:

3DoF for rotational movement around the x, y, and z axes (also known as pitch, yaw, and roll).3DoF for translational movement along those axes, which can be considered as moving forward or backward, left or right, and up or down.

6DoF stands for 'six degrees of freedom' and refers to the ways you can move within and interact with your virtual environment. There are three translational degrees of freedom, and three rotational degrees of freedom.

## Input and Output Devices

Common input devices that add to the user's experience of convincing the human brain that they are present in the VR environment:

1. Joysticks
2. Force Balls/Tracking Balls

3. Controller Wands
4. Data Gloves
5. Trackpads
6. On-Device Control Buttons
7. Motion Trackers/Bodysuits
8. Treadmills
9. Motion Platforms

Controllers are a key part of the overall user experience, especially for virtual reality (VR) applications. VR controllers is integrated with the VR/AR headset to capture natural gestures in order to manipulate objects in the virtual world, thereby allowing the user to interact with the surrounding environment. The core functionality of these devices are the sensors that recognize the location and movement of the user relative to the images displayed on the headset, as well as the real-time communications between these devices. A VR controller must be light, autonomous and ensure comfortable handling. Virtual reality company needs to provides the right products and ICs for this application area where long battery life, high accuracy sensing and wireless connectivity are the key elements to capture and transmit user's movements and actions in real time. Key products include Bluetooth and NFC connectivity solutions, motion, environmental and proximity sensors, power management, wireless charging and low-power high performance microcontrollers.

## 2.2.2 Cloud Architecture and Service

Cloud provides resources and computing services for virtual simulation. Cloud service has a large-scale data processing capability. When running VR educational resources, all tasks are thrown to cloud service, which could greatly reduce the hardware cost of VR.

### Cloud Infrastructure

Cloud(11) provides resources and computing services for virtual simulation. Cloud service has a large-scale data processing capability. When running VR educational resources, all tasks are thrown to cloud service, which could greatly reduce the hardware cost of VR. Cloud infrastructure is a term used to describe the components needed for cloud computing, which includes hardware, abstracted resources, storage and network resources. Think of cloud infrastructure as the tools needed to build a cloud. You need cloud infrastructure in order to host services and applications in the cloud. Cloud infrastructure is not the exclusive domain of third-party public cloud service providers. In fact, all three of the most widely adopted cloud architecture models use the same basic components of cloud infrastructure to deliver computing services. In the private cloud architecture model, the cloud infrastructure is accessed by just a single organization. Private cloud architecture may be developed and maintained by onsite IT staff or it may be delivered by an external service provider. The public cloud consists of third-party cloud service providers who offer cloud resources to paying customers over the internet. Public cloud providers use a multi-tenant environment model to leverage economies of scale and lower the cost of computing power and data storage for their customers. The multi-tenant environment is effective at lowering the overall cost of computing resources, but it may also cause privacy concerns for companies which deal with sensitive data. Hybrid cloud computing environments are defined as private and public cloud systems interacting with each other in a separate, but connected system. Organizations that deal with sensitive data may choose to maintain data privacy by storing some sensitive information in on-site servers while hosting less sensitive applications and other resources in the public cloud where the cost may be lower. Organizations that use hybrid cloud maintain their own private cloud environments, but may leverage public cloud services for additional capacity or computing tasks on a flexible basis.

### Delivery Models

Public cloud service providers deliver cloud infrastructure and related services in three main delivery models:Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS). The three delivery models vary in terms of which parts of the technology stack are outsourced and which aspects the customer will provide.

In the IaaS model, a cloud service provider delivers networking, data storage, servers and virtualization capabilities. The customers gain access to as much data storage and computing power as they need, but they will be required to provide their own software platform to run. This includes operating systems, runtime, middleware, data and applications.

In the PaaS model, a cloud service provider delivers the full cloud infrastructure (networks, servers, data, virtualization) along with a software platform that includes operating systems, middleware and runtime. The PaaS model is meant to provide customers with the capability to develop, test, deploy and operate their own applications in the cloud, without the typical expense and complexity of building an on-site IT infrastructure.

In the SaaS model, a service provider delivers an application through a web-based portal. This eliminates the need for the customer to store any information about the application on their local hard disk - all data storage is located on the servers provided by the service. SaaS companies are responsible for every aspect of the technology stack, from maintaining the cloud infrastructure that supports the application to the application itself.

Cloud infrastructure is made up of several components, each integrated with one another into a single architecture supporting business operations. A typical solution may be composed of hardware, virtualization, storage, and networking components.

### Components of Cloud Infrastructure

#### 1. Cloud Hardware

Cloud foundation is made up of a variety of physical hardware which can be located at multiple geographical locations. The hardware includes networking equipment, like switches, routers, firewalls and load balancers, storage arrays, backup devices, and servers. Virtualization connects the servers together, dividing and abstracting resources to make them accessible to users.

#### 2. Hardware Virtualization

Virtualization is a technology that separates IT services and functions from hardware. Software called a hypervisor sits on top of physical hardware and abstracts the machine’s resources, such as memory, computing power, and storage. Once these virtual resources are allocated into centralized pools, they’re considered as clouds. With the clouds, you would get the benefits of self-service access, automated infrastructure expansion, and dynamic resource pools.

**3. Data Storage**

Within a single data center, data may be stored across multiple disks in a single storage array. Storage management ensures data is correctly being backed up, that outdated backups are removed regularly, and that data is indexed for retrieval in case any storage component fails.

Virtualization abstracts storage space from hardware systems so that it could be accessed by users as cloud storage. When storage is turned into a cloud resource, you could add or remove drives, repurpose hardware, and respond to change without manually configuring separate storage servers for every new initiative.

**4. Networking**

The network is composed of physical wires, switches, routers and other equipment. Virtual networks are created on top of these physical resources. A typical cloud network configuration is composed of multiple subnetworks, each with varying levels of visibility. The cloud permits the creation of virtual local area networks (VLANs) and assigns static and/or dynamic addresses for all network resources as needed. The cloud resources are delivered to users over a network, such as the internet or an intranet, so you can access

### 2.2.3 Engineering Platform for the Laboratory

The Platform meets the requirements of virtual simulation in terms of teaching concept, teaching content, teaching method, research and development and technical operation mode, so as to build a virtual simulation project development and operation.

#### User Interaction Hardware Devices

One of the characteristics of virtual reality technology is the interaction between human and computer. In order to realize the full information exchange between human and computer, special input and demonstration equipment must be designed to affect various operations and instructions and provide feedback information to achieve real and vivid interaction effect. Different items could be used selectively according to practical application, mainly including VR series virtual reality workstation, stereoscopic projection, stereoscopic glasses or helmet display, 3D space tracking positioner, data glove, 3D stereoscopic display, 3D space interactive ball, multi-channel ring screen system, modeling software, etc.

**1. Data sensing gloves**

The observer could also use data gloves and other devices to manipulate the objects in the virtual scene. There are many optical fiber sensors in the data gloves, which could sense the bending state of the finger joints. The observer can interact with the virtual scene through the activities of the fingers. The data glove is a multi-mode virtual reality hardware, which could grasp the objects in the virtual scene through movement, rotation and other actions. The appearance of data glove provides a new interactive means for virtual reality system. The current products have been able to detect finger bending, and use magnetic positioning sensor to accurately locate the position of hand in three-dimensional space. This kind of data glove is called “real glove”, which combines finger curvature test and spatial positioning test. It can provide users with a very real and natural three-dimensional interaction means. In virtual assembly and medical operation simulation, data glove is an indispensable part of virtual reality hardware.

**2. Stereoscopic glasses**

3D glasses are computer devices used to watch 3D games, 3D movies and simulation effects. They are virtual reality stereo glasses based on pagefilp,which divided into wired and wireless. They are the most popular and economical VR observation equipment at present. There are two kinds of stereoscopic glasses based on pagefilp: wired glasses and wireless glasses. Many professional softwares of stereoscopic glasses for graphic workstation support crystaleyes, such as mechanical CAD, product visualization, simulation, molecular modeling, geographic information system / mapping and medical imaging.

**3. Helmet mounted display**

Whether it is required to see the required data at the same time in the real world field of view, or to experience the on-the-spot feeling of whole-body devotion when the visual image changes, simulation training, 3D games, telemedicine and surgery, or using infrared, microscope and electronic microscope to expand the visual ability of the human eye, helmet display has been applied. For example, in military, helmet display can be used for command communication, battlefield observation, terrain and view, night vision system display, vehicle and aircraft gun aiming system and other information display.

**4. 3D space tracker**

3D space tracking positioner is a device used for space tracking and positioning. It is generally used in combination with other VR devices such as data helmets, stereo glasses, data gloves, etc., so that participants can move and rotate freely in space, not limited to fixed space positions, and operate more flexibly, freely and casually. The product has six or three degrees of freedom.

**5. 3D stereoscopic display**

3D stereoscopic display is a new virtual reality product. In the past, stereoscopic display and stereoscopic observation were carried out by wearing stereoscopic glasses with liquid crystal light valve on CRT monitor, and it needs high-tech programming development to realize stereoscopic reality and stereoscopic observation. As long as you have a three-dimensional model, you can realize the three-dimensional display of the three-dimensional model. As long as you use the naked eye to observe the prominent three-dimensional display effect, you do not need to wear any three-dimensional glasses equipment. At the same time, it can also realize the stereoscopic display and stereoscopic observation of video images (such as stereoscopic movies), and it also does not need to wear any stereoscopic glasses.

### Interactive Software Categories

VR is a completely 3D environment created from a combination of software and compatible hardware. This completely immerses the user into the 3D environment, giving them the ability to interact with the virtual world in a seemingly real way. A few steps are required to create an ideal VR user experience. The virtual world is created by software developers and then rendered in a way that users can interact with the objects created by developers. Headsets help to provide users the illusion of being completely immersed in the 3D environment. These 3D objects tend to respond to changes in the user's movement, and the interactions mimic those in the real world. Some certain additional hardware components, such as gloves or other accessories around the room, can also simulate additional senses, such as touch.[1]

Virtual reality is still a young technology, so the different subcategories of the technology are still emerging. The following are some subcategories that are prominent in the space.

1. VR visualization — This type of software allows users to experience aggregated data in a virtual environment. These tools enable users to view the analytics in a way that allows them to fully understand how the data is communicating.
2. VR content management systems — Businesses can use these tools to collect, store, and analyze all VR content in a centralized location.
3. VR SDK — Virtual reality software development kits (SDK) provide the necessary foundation to design, build, and test VR experiences. VR SDKs serve as the building blocks to create basically any VR experience.
4. VR engine — This software provides developers with the essential conditions for creating VR applications, both for terminals and clouds.
5. VR social platforms — Users can collaborate in VR from remote locations using these tools.
6. VR training simulator — These tools can be used in almost any industry to train employees in a completely immersive environment.[2]

### Graphic Interactive Interface

An interface is the set of elements that users interact with to navigate an environment and control their experience. Interactivity in virtual reality is composed of three elements. These are speed, range, and mapping. Speed is the response time of the virtual world. If the virtual world responses to user actions as quickly as possible, it is considered an interactive simulation since immediacy of responses affect the vividness of the environment. Many researchers try to determine the characteristics and components of interactivity of virtual reality in different ways. However, in order to do this perfectly, the designers have to acquire a thorough real-world understanding, meaning that they need to visualize the typical physical space surrounding the user and then build on the elements that they have perused. This is because at any time you do not want your users to feel uncomfortable and feel like the newly introduced elements are invading their personal space. [3]

Take Samsung's Gear VR home screen for example. The Oculus home screen is the starting point for accessing apps, files, features, and connecting others. Whenever the Gear VR application restarts, you are prompted to read the displayed health and safety information and tap the touchpad to accept the terms before continuing. From the home screen you can navigate through tiles by swiping on the touchpad - and tapping will make a selection.The menu at the bottom of the screen will give you access to settings, sharing options and more.

### Typical VR Applications Running Environment

Basic hardware running configurations:

- Video card: NVIDIA GTX660 and above;

1 https://www.g2.com/categories/virtual-reality

2 https://uxplanet.org/designing-user-experience-for-virtual-reality-vr-applications-fc8e4faadd96

3 https://www.g2.com/categories/virtual-reality

- Memory: 2G CPU Processor:I5 and above ;
- RAM: 16G and above;
- HDMI: HDMI 1.4(2880 x 1440,60 Hz) / HDMI 2.0 / DP 1.3 +(2880 ×1440), 90 Hz;
- Hard disk: 100GB SSD or HDD
- USB (I / O): with DisplayPort, USB 3.0 type-A or USB 3.1 type-C;
- Bluetooth: Bluetooth 4.0
- Video rate: The archive version shall not be less than 8mbps, and the network release version shall not be less than 2Mbps (BPS: bits per second);
- Video frame rate: For VR equipment, the best way to run VR is 120fps, and the lowest is 90fps;
- Screen resolution: The submitted archive is made of high-definition pieces, with a resolution of not less than 1920x1080 pixels; the size of a single video file for upload cannot exceed 1GB, for example, if the high-definition video file is too large, it can be compressed into an upload version of not less than 1080x720 pixels;
- Screen refresh rate: Not less than 70Hz;
- Video resolution: The submitted archive is made of high-definition pieces, with a resolution of not less than 1920x1080 pixels; the size of a single video file for upload cannot exceed 1GB, for example, if the high-definition video file is too large, it can be compressed into an upload version of not less than 1080x720 pixels;
- Video file size: There is no limit to the size of the archive film; the size of the uploaded video on the network is less than 500MB, taking 10 minutes as an example;
- Video coding algorithm: H. 264. MP4 (video compression adopts H.264 encoding mode, and package format adopts mp4);
- Image effects: The image is not too bright or too dark; there is no drag and flare phenomenon when people and objects move; other image quality problems; no frame addition, no black field and other errors;
- Field angle: Greater than or equal to 110 degree;
- Number of audio channels: 3D audio surround sound;
- Audio coding algorithm: Linear AAC (Advanced Audio Coding);
- Audio sampling: The sampling rate shall not be lower than 48k Hz;
- Audio and video synchronization:[- 60, + 30] MS, negative value means audio is behind video, positive value means audio is ahead of video;
- Audio rate: Not less than 1.4M bps (BPS: bits per second);
- Audio SNR: More than 50dB;
- Sound effects: Synchronization of sound and picture; no obvious distortion of sound, no obvious noise, echo or other noise, no flickering of volume; clear, full and mellow accompaniment, no obvious imbalance between commentary sound and field sound, no obvious imbalance between commentary sound and background music; no other sound quality problems;
- Clip: Natural clip connection; no blank frame; smooth picture rhythm;
- Post animation: The post production animation shall be designed according to the content, and shall fit the

course content. The display style and the displayed text (non subtitle file) shall be the same.Be able to make mistakes and have the same style in the same course;

Basic software running configurations:

Multiple operating systems supported, including Windows 7, 8, and 10, Linux, iOS, and server operating systems.

**1. For Developers**

Out of hardware configuration, there are two main pieces in software for developing VR experiment: one is the modeling software to create the instrument or laboratory, and then move them into a real-time engine that could turn them into what you can experience in VR.

Modeling Software

Blender is an open source, cross platform modeling animation and rendering tool. It has grown to be incredibly robust and powerful, rivaling the industry names like Maya, Softimage, and 3DS max. The feature set included with the absolutely free product is enough to take you through the entire production pipeline of game creation.

Storyboard VR is a cost-free visualization app which you can use to design, arrange, and combine 2D assets. You can make use of it by creating VR prototypes, drawing environment outlines, and building storyboards. In essence, Storyboard VR is perfect for designers and architects who want to capitalize on their first sketches and exchange ideas with colleagues early on in the creation process.

Real-time Engines: most popular VR development engines are Unity and Unreal. Unity 3D is a commercially available game engine mostly used for game development in 2D and 3D. It also finds its utility in non-gaming solutions where simulations are used. Power, flexibility and simplicity are the three core salient features that makes Unity so popular. Developers can deploy them across mobile, desktop, VR/AR, consoles or the Web, and connect with players and customers.

The Unreal Engine is very well known in the games industry. This package is incredibly versatile, allowing for creation of games from 2D hand drawn looking platformers up to cinematic almost movie like experiences. They've charged into virtual reality head-on and support the latest technologies natively. There is a built-in marketplace where you can find and purchase assets to include in your projects and a very large community sharing tutorials and inspiration.

Besides, in most cases, the IDE (Integrated Development Environment) is quite common as developing other non-VR applications. You can use Visual Studio, Xcode, Eclipse, and so on, as well as the programming languages like JAVA, .Net or PHP, which basically depends on your requirements.

**2. For Users**

For most VR application, it is supported to run on multiple operating systems, including Windows 7, 8, and 10, Linux, iOS, and server operating systems.

If the virtual lab application is running on web, you should first check if your browser support WebGL, which enables your browser to run 2-D and 3-D rendering natively without installing any additional plugin. It also enables the browser to use the hardware GPU to perform graphic calculations instead of your CPU. This means the graphic rendering would work better and most importantly it would work.

Some online VR experiments may have a basic requirement of bandwidth, especially for the application that communicates between client and server, so users should also check if their bandwidth is enough for running the application.

# 2.3 Infrastructure Architecture

## 2.3.1 Hardware Configurations

### Head-mounted device hardware configurations

Typical HMD basic device parameters:

**1. Video rate**

The archive version shall not be less than 8mbps, and the network release version shall not be less than 2Mbps (bps: bits per second);

**2. Video frame rate**

For VR equipment, the best way to run VR is 120fps, and the lowest is 90fps;

**3. Screen resolution**

The submitted archive is made of high-definition pieces, with a resolution of not less than 1920x1080 pixels; the size of a single video file for upload cannot exceed 1GB, for example, if the high-definition video file is too large, it can be compressed into an upload version of not less than 1080x720 pixels;

**4. Screen refresh rate**

Not less than 75Hz;

**5. Video resolution**

The submitted archive is made of high-definition pieces, with a resolution of no less than 1920x1080 pixels; the size of a single video file for upload cannot exceed 1GB, for example, if the high-definition video file is too large, it could be compressed into an upload version of not less than 1080x720 pixels;

**6. Video length**

5-15 minutes for each video, which could be adjusted according to the needs of the teacher, but not more than 15 minutes;

**7. Video file size**

There is no limit to the size of the archive film; the size of the uploaded video on the network is less than 500MB, taking 10 minutes as an example;

**8. Video coding algorithm**

H.264. MP4 (video compression adopts H.264 encoding mode, and package format adopts mp4);

**9. Image effects**

The image is not too bright nor too dark; there is no drag and flare phenomenon when people and objects move; other image quality problems; no frame addition, no black field and other errors;

**10. Field of view (FOV)**

Humans have an FOV of around 180°, but most HMDs offer far less than this. Greater than or equal to 110 °;

**11. Number of audio channels**

3D audio surround sound;

**12. Audio coding algorithm**

Linear AAC (Advanced Audio Coding);

**13. Audio sampling**

The sampling rate shall not be lower than 48Khz;

**14. Audio and video synchronization**

[- 60, + 30] MS, negative value means audio is behind video, positive value means audio is ahead of video;

**15. Audio rate**

Not less than 1.4mbps (BPS: bits per second);

**16. Audio SNR**

More than 50dB;

**17. Sound effects**

Synchronization of sound and picture; no obvious distortion of sound, no obvious noise, echo or other noise, no flickering of volume; clear, full and mellow accompaniment, no obvious imbalance between commentary sound and field sound, no obvious imbalance between commentary sound and background music; no other sound quality problems;

**18. Clip**

Natural clip connection; no blank frame; smooth picture rhythm;

**19. Post animation**

The post production animation shall be designed according to the content, and shall fit the course content. The display style and the displayed text (non subtitle file) shall be the same.Be able to make mistakes and have the same style in the same course;

**20. Subtitle requirements**

The English teaching video provides corresponding English subtitles, which is a combination of Chinese and English. In the whole sentence, there are at most 20 words and no more than 40 letters;

**21. Subtitle file format**

Subtitles cannot be fixed on the video and must be provided in a separate SRT file format;

**22. Subtitle coding**

Chinese subtitles must be UTF-8 encoded;

**23. Subtitle timeline**

The time axis is accurate, and the subtitle appears at the same time as the video sound;

## Cloud server configurations

In computing, the client–server model architecture is a computer program or a device that provides functionality for other programs or devices. The computer providing the service is called the server, and computer accessing the service is called the client.

Servers can provide various functionalities, often called “services”, such as sharing data or resources among multiple clients, or performing computation for a client. A single server can provide services for multiple clients, and a single client can access multiple servers. A client process may run on the same device or may connect to a server over a network on a remote device. Typical servers are classified as database servers, file servers, mail servers, print servers, web servers, game servers, and application servers.

Hardware servers requirements vary widely, depending on the server’s purpose and its applications. Further more, the hardware configurations of the server are far more advanced than the client hardware configurations. Therefore, servers are usually more powerful and expensive than the clients hardware.

Servers usually run unattended without a computer monitor or input device to operate. Usually,servers are configured and accessed over the networking by client computers. Many servers do not have a graphical user interface. The management is often operated remotely and conducted via various methods including PowerShell, SSH and browser-based management systems.

## Large servers

Large traditional single servers need to run for long periods without any fault. Availability would have to be extremely high, and hardware reliability and durability is critical to the server functioning and performance.

Mission-critical enterprise servers would be very fault tolerant and use specialized hardware to reduce the low failure rates, for example, uninterruptible power supplies are often incorporated to safeguard against power failure.

Hardware servers are typically equipped with the hardware redundancy such as dual power supplies, RAID disk systems, and ECC memory, along with extensive pre-boot memory verification. Critical components might be hot swappable, allowing mantaince engineers to replace them on the running server without shutting down, and to guard against overheating, servers might have more powerful fans or use water cooling.

Hardware servers will often be able to be configured, powered up and down or rebooted remotely, using out-of-band management.Server casings are usually flat and wide, and designed to be rack-mounted, either on 19-inch racks.

These types of servers are often housed in dedicated data centers. These will normally have very stable power and Internet and increased security. Noise is also less of a concern, but power consumption and heat output can be a serious issue. Server rooms are equipped with air conditioning devices.

### Clusters

A server cluster is a collection of computer servers maintained by an organization to supply server functionality far beyond the capability of a single server. At present, the advanced data centers in the world are often built of very large clusters of much simpler servers,and this is a collaborative effort.

The cloud is commonly used to refer to several servers connected to the internet with virtual software and some application software installed, providing the computing services. Cloud-based services can include web hosting, data hosting and sharing, and software or application use. The clusters can is capable of providing the reliable, scalable and effective service for clients.

Cloud servers are commonly created using virtualization software to divide a physical server into multiple virtual servers. Organizations use an infrastructure-as-a-service (IaaS) model to process workloads and store information. They can access virtual server functions remotely through an online interface.

## 2.3.2 Network Bandwidth and Transmission Parameters

The cloud storage provides the most fundamental part of data storage. The storage device can be fibre channel storage device, IP storage device such as NAS and iSCSI, or SCSI or SAS Das storage device.

Basic management layer, which is the core part of cloud storage, is also the most complex part of cloud storage.

Application interface layer is the most flexible part of cloud storage.

It is noted that different cloud storage operations can provide different application service interfaces according to the actual business types. For instance, video monitoring application platform, IPTV and video on demand application platform, network hard disk application platform, remote data backup application platform.

## 2.3.3 Network Bandwidth and Transmission Parameters

Under normal network conditions, 2K video needs 4mbp bandwidth on average, while 4K video needs 18mbp, and the network transmission rate should be greater than 10m/s as much as possible.

Network latency between 20 to 40 ms can meet the requirements of Cloud VR video services. Latency only affects the loading time. However, strong-interaction Cloud VR services pose the following latency requirements to ensure user interaction and pleasure:

### Fair-experience phase

In the fair-experience phase, latency within 70 ms is acceptable. Black edges and quality deterioration are acceptable.

### Comfortable-experience phase

In the comfortable-experience phase, latency within 50 ms is acceptable. In this case, black edges are eliminated.

#### Ideal-experience phase

In the ideal-experience phase, latency within 30 ms is acceptable, image distortion is unnoticeable when users move.

1. The MTP latency must be ≤ 20 ms (the latency depends only on the processing speed of the terminal and has nothing to do with the network in the case of asynchronous rendering between the cloud and terminal).
2. The requirements on cloud rendering and streaming latency are as follows:
3. The acceptable operations latency is ≤ 100 ms. The operation latency includes cloud rendering and streaming latency, latency caused by the secondary rendering on terminals, and latency caused by asynchronous time warping and screen refreshing. The maximum latency caused by cloud rendering and streaming is 70 ms. Therefore, the minimum remaining latency is 30 ms, which is greater than the latency caused by asynchronous time warping and screen refreshing for MTP. Therefore, meeting cloud rendering and streaming requirements meet the operation latency requirement.

## 2.4 Middleware Layer

The concept of middleware is not the definition of the so-called middleware software. Here refers the software tools and layer that between the VR device low-level driver and the application software. The middleware layer consists the 2D and 3D graphic development tool, and other related software.

### 2.4.1 Virtual Model Development Workflow Engine

It is essential for the VR to create the virtual and simulation model. The work flow is as the following:

**1. Virtual Model**

First step is to use a 2D or 3D CAD tool to develop a virtual and simulation model, also known as a digital prototype, to form the basic design. Provision of 3D objects from inside the virtual environment.

**2. 2D/3D mesh**

Second step is create a 2D or 3D mesh for analysis calculations. By using automatic algorithms users can create structured meshes to maintain control over element quality.

**3. Results analysis**

Third step is to perform finite element analysis, review results, and make engineering judgments based on simulated experimental results.

In terms of visualization and interaction,it is expected to have this objectives including:

1. Provision of 3D model objects from inside the virtual environment without having to import such objects from an external thermal tool system.
2. Provision of simulating the experimental objects from inside the virtual and simulation environment.

3. Improved interaction techniques that substitute the real world interaction, graphics rendering systems that generate high quality stereo images, and realistic behavior of objects in virtual and simulated environments.

## 2.4.2 Simulation and Virtual Middleware Software

### Visualization

Data visualization, simply put, is the graphical representation of data. It has become a necessary and integral part of data science today. As technology makes a promising drive virtual and augmented reality, it is essential that users can experience data visualizations in AR/VR as well.

Here only introduces some of the technology for the data visualizations creating in virtual reality.

**1. WebVR**

WebVR is the JavaScript application programming interface that provides support for virtual reality devices. It is an open technology specification that also makes it possible to experience VR in a browser. In most cases, two things are needed to experience WebVR: a headset and a compatible browser.

**2. A-Frame**

A-Frame is based HTML technology, so it is simple to get started. The core is a powerful entity-component framework that provides a declarative, extensible, and composable structure. A-Frame can be developed from a plain HTML file without having to install anything.

### Modeling and assembly

Simulation modeling is the technology of creating a digital prototype of a physical model to simulate its performance in the real world. Simulation modeling is used to help designers and engineers understand whether the experimental result could fail or not. Simulation modeling can also help to predict fluid flow and heat transfer patterns. It analyses the approximate working conditions by applying the simulation software. One aspect of current efforts in computer simulation is the attempt to simulate "reality". Today, what is achievable is virtual "reality", an immersive environment where a participant understands that what he is experiencing in not the actual reality. Virtual Reality uses VR headsets to create realistic sensations. In the simulated environment,participants can interact and move around. A similar system is augmented reality, using a camera feed or a computer or a smartphone screen.

Assembly modeling is a technology used by computer-aided design and product visualization computer software systems to handle multiple files which represent components within a product. Virtual reality and assembly simulation are both technologies which are established in their respective application fields. Using simulation for assembly and factory planning is well-known and its usage is further encouraged by the visions of the digital factory. The role of assembly modeling in achieving the full benefits has led to ongoing advances in this technology.

## 2.5 Application Layer

Application layer includes teaching guidance, service description, service registration and service retrieval four modules.

**1. Instructional guidance**

The instructional guidance should be based on the experimental teaching guidance rules, experimental operation feedback and prompt rules. According to the experimental operator's operating behavior ietc.n the system, the corresponding guidance and prompt items should be triggered, so as to give the operator hints and guidance on the subject knowledge and skills related to the experiment.

**2. Service description**

Virtual experiment teaching system, the application of service can be a system, can also be a third-party development, unified service description used to describe the method and the description model, all kinds of services to access the virtual experiment system for standardized description and explanation, to increase access to the application of virtual experiment teaching system service utilization and recognition.

**3. Service annotation**

Service registration refers to the service developed by the developer of the virtual experimental teaching platform, or the service application developed by a third party, which is connected to the virtual experimental teaching platform in a loosely coupled way and integrated into the virtual experimental teaching platform, so as to realize the data reading and exchange between the external service and the virtual experimental teaching platform, as well as the interoperability between the systems.

**4. Service retrieval**

Service retrieval is an information search and query function established in order to improve the retrieval efficiency and utilization rate of various services on the virtual experiment platform. It is recommended to set the classification retrieval identification according to the use object, subject and function of the virtual experiment application service.

### 2.5.1 Types of Virtual Reality Application Software

The virtual world is created by software developers and then rendered in a way that users can interact with the objects created by developers. The most common VR experience comes from downloading an application software from an app store. Once the download has completed, you can run it in a compatible VR device. For those who don't want to download the app from the app store, web-based VR could be another way. It enables users to access VR through the browser, just like a webpage.

#### App-based VR

To start with, an app is piece of software designed to fulfil a specific set of needs. With that, a virtual reality app is just an app which uses the power of virtual reality to reach its goals.Once the app has download, typically from an app store such as the Oculus Store or Google Play, the experience is playable with a VR headset specific to that app.

### Web-based VR

Web-based VR brings virtual reality technology to the web page, making it easier for anyone to create, enjoy, and share VR experiences. With WebVR, you can press a browser and launch the VR by clicking a link, no matter what VR devices you have.

## 2.5.2 Virtual Experiments Resource Management

### Management of VR Devices

Management of virtual reality devices is a very important step on carrying on the virtual and simulation experiments. As organizations move towards virtual reality-based training programs, they can use the endpoint management technology to lock down VR devices into kiosk mode, ensuring that they are used only for training purposes. With VR device management, it can be ensured that content and apps are remotely delivered on the VR devices. Instructors or IT admins can remotely view the VR screen from their computer browser using the remote screen sharing functionality,reducing device maintenance time and costs.

The experimental resource management and monitoring system is a set of enterprise level system with complete functions. It takes the test task management, test process management and test resource management as the core, with supporting interface, safety and other management functions. It can also have other functions on the basis of data management. Test resource management can manage, schedule and count all kinds of resources used in the test. The specific functions are as follows:

**1. Equipment management:**

It provides the functions of equipment initialization, basic information of equipment account, maintenance, measurement, period check, repair, fault handling and use record.

**2. Sample management:**

It provides sample basic information, ex warehouse, in warehouse, label, sample bag, post-test processing, sample removal, use record management functions.

**3. Consumables management:**

It provides consumables classification, basic information, purchasing, warehousing, labeling, outbound, early warning, inventory, use record functions.

**4. Standard material management:**

It provides the functions of standard material classification, basic information, purchase, warehousing, labeling, outbound, early warning, inventory, use record.

**5. Supplier management:**

It provides the functions of supplier classification, supplier basic information, new, query, modify, delete and evaluation.

**6. Personnel management:**

It provides personnel technical files, qualification authorization, training and time management functions.

Summarize the operation data and information involved in the experiment business, including the status and usage of experiment resources, the execution status of experiment plan, the execution status of experiment task, the abnormal situation of experiment and the usage of experiment cost. At the same time, the management data needed for the time, cost and completion rate of the experiment are automatically counted to form an effective comprehensive decision support platform for the experiment. The experimental resource management system conforms to and complies with the standards of various countries, and provides the audit of data records, management of technical documents, management of subcontractors, and other audit management functions. Improve the standardization degree of quality management and quality assurance in laboratory test process to ensure traceability of all works.

### 2.5.3 Virtual Experiments for Tutoring

Online tutoring students can eliminate the waste of time traveling between appointments, which can often eat up valuable tutoring hours.

In this section, we will show how virtual and simulation experiments serve for tutoring in real life.

#### Virtual whiteboard

As for the science and math, or other complex subjects, it's critical to simulate the experience of sitting next to astudent, crowded around a single exercise on paper or in a book. With the introduction of the e-learning terminal devices and a lot of networked whiteboard apps, everything changed.

Virtual whiteboard apps can satisfy a few situations:

**1. Real-time**

You and the student are looking at the same document, with a minimal network lag time.

**2. Simultaneous**

Multiple people can edit the document at the same time.

**3. Flexible**

Allows you to upload any document to be used as the background for the lesson.

**4. Persistent**

Whiteboard sessions are stored, so that either you or the student can review the lesson afterwards.

#### Screen recording

Recording sessions with students to help student review the lesson later on. It's also a useful way to self-evaluating your own teaching methods, so as to make improvements.

#### Homework assignment

Tutors will assign students homework or practicing to reinforce the information the tutor's been teaching. To achieve it, tutors usually use Word documents, but as online tutoring evolves, more tutors are using web products and mobile applications to help assigning homework.

Chapter 6 in this guide will describe the process in details.

### 2.5.4 Assessment for the VR Experiment

Virtual reality technology provides an exciting tool to gather evidence for ecological relevance that goes beyond traditional cognitive assessment. It enables researchers to observe behaviors in simulated real-life settings with participants less aware of the examiner while immersed in the simulated environment.

VR assessment, the innovative method, also provides increased levels of experimental control compared to traditional method. The VR head-mounted display tracks and records the participants' head movements, allowing for more objective behavioral assessment of off-task behavior and hyperactivity.

### 2.5.5 Experiment Reporting and Analysing

Virtual experiment has a good role in teaching, not only can help students better understand knowledge points, but also can help teachers solve many inconveniences in real experiments. The report and analysis of the virtual experiment will be explained by examples.

The virtual reality technology and the construction of virtual experimental environment enables students to understand the abstract teaching content more intuitively and thoroughly. Virtual reality of curriculum development and the construction of teaching materials, which can not only reduce the experimental consumables expenditure, save experiment cost, but also provide students with a learning guide, sample video and interactive practice integrated learning environment. It can fully mobilize the enthusiasm, initiative and creativity of students, and play an important role in cultivating students' creative thinking ability, rigorous and realistic scientific attitude and independent work ability.

Virtual reality technology is different from traditional simulation technology. It provides people with a completely new way of human-computer interaction, and has made a qualitative leap in technological thinking. It integrates the simulation environment, visual system and simulation system. The operator interacts with the virtual environment through the sensing device to obtain multi-dimensional perception of vision, hearing, touch, etc., and changes the virtual environment according to the willpower of the operator. The unique characteristics of virtual reality technology will make this technology play an important educational teaching value in college experimental teaching.

**1. Authenticity**

Modern practice teaching methods using virtual reality technology can create virtual situations and transform the traditional single teaching model into an interactive and participative teaching model. Virtual teaching software can not only make some abstract problems such as concepts, relationships, principles, etc. macro, but also simulate the difficult presentation techniques and operating skills that are difficult to complete in conventional classroom teaching, simplify complex problems, and help students understand, Memorize and master motor skills.

**2. Multi-perception and process immersion**

Virtual reality is more scalable, and it includes various interactions and combinations with various application systems. Based on multi-perception, virtual reality technology can improve the user's feeling of reality in a simulated environment, enabling students to operate experimental instruments and observe experimental phenomena as if they were immersive, thereby accurately verifying experimental hypotheses and more effectively cultivating students' practice Ability and innovation ability.

**3. Intelligence and fun**

The goal of experimental teaching is to cultivate students' practical skills.Mastering of practical skills could be divided into four stages: operation orientation, imitation, integration and proficiency.Four steps require students to explore and gradually clarify the experimental content and experimental steps in the actual operation process. Virtual reality teaching technology can track and feedback students' practical teaching effects in time.Similar to an invisible teacher providing personalized guidance at any time beside the students, it helps to help students build the correct image and display the directional image in the mind. Practical actions are shown. Virtual reality technology has a strong interest in itself due to the situational nature of the performance process, the authenticity of the content, the diversity of presentation methods, and the intelligence of the technology. It encourages learners to actively participate and effectively feedback, and actually carry out" Teaching according to aptitude."

**4. Interactivity and imagination**

Interactivity refers to the degree to which students operate the scene in the virtual environment and the natural degree of feedback (including real-time). Conception can broaden the students' cognitive scope, so that the experiencers can acquire knowledge and be inspired according to their own feelings. In virtual reality scenes, students can not only complete specified tasks in accordance with experimental operation specifications, but also creatively verify their whimsy.

# Chapter 3 Deployment of Virtual and Simulation Laboratory

To support a virtual and simulation experiment, an environment should be established. The Virtual and Simulation Laboratory is a Smart Learning Environment for virtual and simulation experiment. In this chapter, the deployment of Virtual and Simulation Laboratory will be introduced. The first section is lab design based on learning experience, including empowering lab by VR, integrating technologies, acquiring and analysing data, and the demand of learning experience. The second section is VR resource generating and sharing. It consists of measuring cognitive load, generating and sharing VR resource. The last section is the deployment process of a prototyping learning space, building smart classroom, and installing platform for virtual and simulation experiment. Platform engineering and resource development for virtual and simulation experiment will be introduced in detail in the following two chapters. Figure 3.1 indicates the flow of the environment preparation for virtual and simulation experiment.

## 3.1 Lab Design Based on Learning Experience

To support a virtual and simulation experiment, the first step is to design a Smart Learning Environment based on the demanding of learning experience, which is empowered by VR, and integrated with technologies to acquire and analyse data for effective learning.

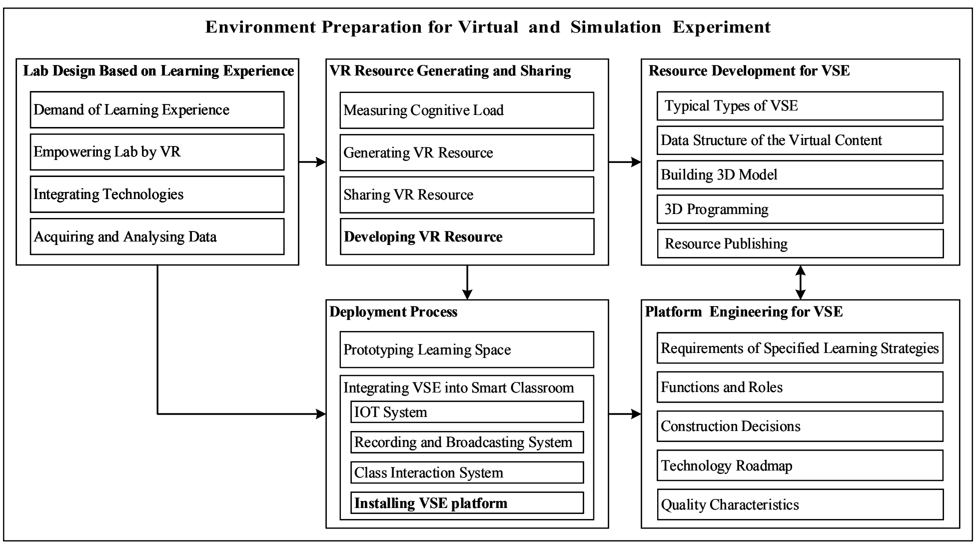


Figure 3.1: The Flow of Environment Preparation for Virtual and Simulation Experiment

### 3.1.1 Demand of Learning Experience

Students need a learning space for easy, engaged and effective learning, which makes a great learning experience (12). Virtual classroom technology will bring more encouragement to learners and enhance the effectiveness of the learning process.

The learning experience(13) is very important when deploying the virtual technology, application and demonstration to labs, which takes the learners as the center of instruction process. Learning space design concept and mode should be used to build the virtual and simulation laboratory. It should conduct collection of the effectiveness of tutoring and learning, and provide feedback on information and interaction for learning space design and evaluation of virtual and simulation laboratory.

Learning experience is a suitable aspect to evaluate the virtual and simulation labs. The learning space evaluation system could provide real-time information acquisition tools, cloud services for learning space, and use some online evaluation surveys to obtain the learning experience in the lab. By cloud service mode, the learning space evaluation system could be deployed with open cloud acquisition interface. The monitoring and collection content of equipment and environment is transferred to the cloud. The data analysis is carried out in the cloud to form the multi-dimensional evaluation information. The online evaluation service should be provided by SaaS.

### 3.1.2 Empowering Lab by VR

The virtual and simulation lab must have a certain area at least. For example, according to the standard of 45 students per class in primary and middle schools, the average classroom area is no less than 1.13 square meters per person, and the calculated standard area is at least 50.85 square meters in order to form the virtual and simulation laboratory. The classroom is mainly used to support the comprehensive virtual and simulation experiment with high immersion learning environment.

Installation and deployment of virtual and augmented reality equipment makes the lab be empowered to realize virtual and simulation experiment, including high immersion display equipment, high fidelity playback system, augmented reality equipment, natural interaction and force feedback equipment, holographic equipment, etc. Specifically, it includes wearable input devices, handheld operating controllers, gesture recognition devices, motion capture devices, VR/AR glasses and multi-channel headphones. Those equipments and systems could realize visual, auditory and tactile simulation. The virtual experiment system, VR resource management and play system and other related software will support integrating technologies for easy, engaged and effective learning.

### 3.1.3 Integrating Technologies

VR should be integrated with other technologies in classroom, including multimedia system, online live broadcast and recording system, physical environment perception, classroom control system, learning process recording and analysis, human-computer interaction system, scenario analysis system, etc. Tablet PC and other network access equipment for online learning environment are the end of the system and services, they should also be equipped. When integrated with suitable technologies, the virtual and simulation laboratory not only can support basic instruction for experiment, but also is a technology integrated environment for smart learning. With terminal equipment and tools in the learning space, the lab can be a remote virtual learning space, builds intelligent perception, monitoring, controlling and interaction environment that is the fusion of virtual and physical learning space to be a Smart Learning Environment that leads data acquiring and analysing smoothly.

### 3.1.4 Acquiring and Analysing Data

With cloud services, the data collection and analysis of the virtual and simulation could be formed spontaneously. The functions of the environment is mainly about equipment monitoring, behavioural analysis, identity recognition preparation, process analysis and dashboard with visualization. The methods of educational data mining and learning analytics will give guidance to related personnel on how to acquire and analyze data(14).

The emotional analysis system, environmental monitoring system, human wearable devices, data processing and analysis and super large screen are the main devices. Systems and services of the environment are used mainly for supporting the collection, analysis and processing of multi-dimensional information of physical environment, learners and tutors. The results could prompt learners and tutors to improve effectiveness of learning and tutoring through iterative and mutual optimization.

## 3.2 VR Resource Generating and Sharing

Generating and sharing of VR resource are other main functions of the virtual and simulation laboratory. To generate VR resource of particular contents, the cognitive load should be considered first. Learning resources must be generated with suitable cognitive load and be shared with a friendly platform.

### 3.2.1 Measuring Cognitive Load

If the cognitive load(15) is too high, learners would hardly extract primary knowledge and get skills from the contents. Cognitive load analysis tools with cognitive load measurement methods is an important part of virtual and simulation laboratory. The cognitive load analysis and assessment tools measure the interaction of multi-channel cognitive load and information overload in virtual and simulation laboratory, could form an effective assessment and analysis tool set and apply it to the analysis of learning space, which will enhance learners' self-identity.

### 3.2.2 Generating VR Resource

Many useful tools could be used to generate VR resource. VR resource generation and development tools are with the use of 3D scanning equipment, 3D camera, artificial modeling and other techniques which could achieve generation of resources rapidly. 3D reconstruction tools use 3D cameras to shoot 360-degree surround footage in real time and could complete panoramic 3D content production. Tools supporting 3D scanning equipment could quickly generate 3D data in the real world in virtual space and could be applied to the production of highly realistic VR content. Tools supporting rapid modeling could generate and develop VR learning resources using 3D model libraries, sketches and interactive modeling rapidly.

### 3.2.3 Sharing VR Resource

VR resource management and storage tools could realize the organization and management of massive VR learning resources. The online VR resource sharing service platform can support browsing, accessing, downloading and displaying the resources by registered users and ordinary users by the Internet. Authorized users can upload, publish and share the VR resource. Also the VR resource sharing services are accessible online.

## 3.3 Deployment Process

The entire deployment process of virtual and simulation laboratory includes prototyping learning space, integrating virtual and simulation experiment into smart classroom, and installing the platform for virtual and simulation experiment.

### 3.3.1 Prototyping Learning Space

3D modeling design software is used for learning space design. It could quickly simulate real classroom or existing learning space by using learning space design and construction technology. The new model of learning space is built quickly by means of virtual reality and simulation. It will realize the rapid judgment of learning spatial form. The cloud service platform for learning space design may appear in recent times, which deploy 3D modeling and design services for learning space through cloud, i.e. soft as a service(SaaS).

### 3.3.2 Integrating VSE into Smart Classroom

Smart classrooms could technologically enhance tutoring and learning(16). Smart classroom can be the foundation of a virtual and simulation laboratory, virtual and simulation technologies could be integrated. Integrating virtual and simulation experiment into a smart classroom could make a virtual and simulation laboratory. Experiment and learning can be really fun when learning subjects and learning content are interesting. Tutoring and learning could be growing together as long as the labs are integrated learning analysis techniques and equipped with a specialised software and systems.

Effective learning has become an essential concept in learning environment. Technologies have entered every aspect of our lives and industries. Learners and tutors could make the most of such developments for facilitating learning. With suitable learning technologies, a smart classroom will enhance instruction and attract attention span of students and give opportunities to the existing traditional classroom. The opportunity to provide students with effective learning by helping them understand concepts better, which could increase their engagement and achieve academic excellence. The basic systems and services of smart classroom are as follows.

#### Iot System

The Iot system is based on computer network and wireless communication technology, comprehensively applies Internet of things(17) technology, sensor technology and automatic control technology to build a safe, green and intelligent classroom environment.

First of all, the Iot system leads the management to all devices and equipment efficiently. It connects all classroom equipment and devices with network, so all devices could be controlled locally or remotely. The intelligent identification, tracking, monitoring and management could make the equipment and device management more efficient and convenient. For some learning and tutoring situations, the control of devices and systems can be done by one button, which is very convenient for learning and tutoring.

Secondly, the Iot system could supply a very suitable environment for learning. With classroom environment perception and automatic adjustment, Iot can achieve intelligent management of the environment and provide a green and healthy environment for tutors and learners. For example, the adaptive adjustment of light in classroom is beneficial to the protection of students' eyesight.

Thirdly, the Iot system could make the environment safer. It could build an unattended space with real-time monitoring of the entire classroom environment. The system could notify relevant staff to ensure the safety of personnel and equipment by prompt detection of safety hazards. With the centralized control mode, the management and maintenance of campus equipment could be facilitated with system operation and functions maintenance.

Last but not least, the Iot system could facilitate the integration of smart classroom. The system gateway and device terminal can all be adopted with ZigBee wireless cellular communication mode, which will overcome many disadvantages brought by wired central control system. The learning space doesn't need to re-slot wiring, doesn't change the classroom original weak and strong circuit layout, and greatly saves the construction cost and construction time. Thus the deployment doesn't need the professional engineers, it could be done by the general staff. Further more, power lines do not need to be connected with central control equipment, it ensures the personal safety of tutors and students.

### Recording and Broadcasting Syste

The functions of recording and broadcasting system have been normalized from many providers. The main functions are as follows.

1. Supporting a panoramic view of the tutors, students and close-up image acquisition.
2. Supporting synchronous data acquisition of blackboard writing features.
3. Tracking tutors and students who are asking, answering, and moving.
4. Recording the lessons automatically with abatement of noise and improving the efficiency of the tutor course video production.
5. Accumulating valuable video resources for online education.
6. Providing live interactive courses and selected recorded courses.

The interactive recording system is designed to create an interactive environment.The interactive recording software is installed on the classroom computer, and the panoramic close-up of tutors and students, including the interactive process of tutors' characteristics, students' perspectives, multi-channel audio and video signals, which could realize local and remote synchronous classroom. Through real-time interaction, students and tutors in different regions could learn from each other remotely. Uploading the recorded files to the cloud platform, and managing the files centrally through the resource platform software could meet the requirements of sharing, publishing, storage, voD and live broadcasting. The resource platform is also equipped with personal space and other functions, which can realize personal data conservation, document management, class evaluation, class tour rating and other requirements. Senior leaders and experts could also observe and comment on high quality courses, academic exchanges, tutoring and research activities.

### Class Interaction System

The class interaction system is mainly for facilitating interaction in class, including interaction among students and between tutor and students. Interactive display, collaborate supporting system and tutoring app are useful tools. They can serve the teachers' strategies and styles and students' perception, understanding, and effective participation in different classroom skills(18).

Interactive displays are used to showcase dynamic interactive multi-media content on any LCD screen, plasma screen or glass storefront window. With extension devices, the contents in any smart devices with the same WiFi in the classroom can share contents to the display. It makes discussion and sharing more convenient. Collaboration within a class also becomes very easy with the interactive display. Tutors and students can come and collaborate on the multitouch featured interactive display from their dedicated devices and push their thoughts or doubts on to the display for everyone in the class.

Tutors could also collect the feedback of students naturally. They could push the pre-class preview courseware, videos, exercises and other learning materials to students' mobile phones, so that tutors and students can communicate and give feedback timely. In class, real-time answering bullet screen interaction provides a perfect solution for the traditional tutor-student interaction in classroom tutoring. The application covers every tutoring process including before class, during class and after class scientifically. Inclusive three-dimensional data support for tutors and students is also provided, which make personalized report, automatic task reminder, and learning more clear.

### Installing VSE platform

VSE platform is a set of basic experimental platform which is specially designed for the construction and operation of virtual simulation project. The software conforms to the requirements of virtual simulation, including teaching concept, teaching content, teaching method, research and development technology and operation mode, so as to develop a virtual simulation project and build a basic operation platform for the school. It consists of the following parts:

1. A high performance image generation and processing system with high performance GPU driven display.
2. A immersive virtual 3D display system, such as high-definition monitor, VR headset.
3. A virtual reality interactive system, for example multi-modal interactive devices.
4. Integrated application control system. It integrates other subsystems and resources to assist tutors' tutoring work and provides a set of operating cloud platform for tutoring which can carry out simulation experiment in the experiment. Unlike other subsystems, it requires customized development based on experimental content, which will be introduced in detail in the next chapter.

# Chapter 4 Platform Engineering for Virtual and Simulation Experiment

Different from hardware and equipment, the platform for virtual and simulation experiment should be customized to different tutoring concepts, learning contents, instructional strategies, and etc. So the platform must meet the requirements of virtual and simulation experiment. In this chapter, platform of engineering will be introduced. It is a technical guidance for constructing an agile software to support virtual and simulation experiment with suitable soft engineering methods. First of all, this chapter introduces the requirements of virtual and simulation experiment, including instructing experiment process, employing instructional strategies, and supporting personalized learning. Then this chapter explains functions and roles in the platform, including management, plan making, learning, tutoring and corresponding roles and workflows. The third section explains some construction decisions about how to select infrastructure, choose programming language, determine development framework and combine soft development methods. And the next is the technology roadmap of designing a layered architecture, setting the data layer, building data access layer, constructing business logic layer and implementing the presentation layer. Last but not the least, the characteristics of software quality will be discussed from both users and developers.

## 4.1 Requirements of Specified Learning Strategies

Tutoring experiment process, employing instructional strategies, and supporting personalized learning are mainly requirements of specified learning strategies for virtual and simulation experiments.

### 4.1.1 Tutoring Experiment Process

The tutoring service should integrate information, resources, personnel and facilities received by tutors and learners during the experiment process. Learning efficiency and tutoring quality must be guaranteed by a suitable virtual and simulation platform, which trys to make students achieve a better academic performance. By analyzing the data from all kinds of sensors with artificial intelligence, the behavior of learners and tutors could be tracked. Fine-grained analysis of behavior in some particular scenarios will allow for personalized requirements, which could push learning contents, partners, and other resources to the user with adaptive algorithms.

### 4.1.2 Employing Instructional Strategies

To meet the requirements of virtual and simulation experiments, the platform should support employing instructional strategies, such as problem-based learning, inquiry-based learning, etc. They advocate autonomy, cooperation and engagement. Different kinds of practical tutoring methods should be built within the platform, including theoretical explanation, case analysis, problem discussion, process exercise, knowledge contest, human-computer interaction, brainstorming, interactive game, confrontation building, live-action exercise, remote discussion and so on.

### 4.1.3 Supporting Personalized Learning

Growing up in the digital environment, the new generation of learners have raised a higher demand for learning. Learning at unified pace and in fixed time and place has being broken. They are keen to learn at their own pace in anytime and anywhere. The intelligent assistant services will make the above learning methods possible. First of all, AI could acquire the learning behavior data and provide learners with appropriate learning resources and paths with the help of big data and learning analysis. Secondly, provided with an immersive virtual learning environment, learners could participate in learning at any time and in any place. At last, by promoting the change of learners' cognitive level and emotional state, learners could participate in learning activities with a positive attitude.

## 4.2 Functions and Roles

There are many functions in virtual and simulation experiment supporting services. They could be grouped as management, plan making, learning and tutoring. There are mainly four roles to deal with those functions: system administrators, educational administrators, tutors and learners(19). And there are many workflows crossing the functions and rows, including user management, course management, course information review, course plan review and the information interaction between them.

### 4.2.1 Management and Plan Making

Management and plan making are the main functions for administrators. System administrators make sure that the data in the system could normally flow, and educational administrators plan and accelerate experiments by supporting learners and tutors with services provided by the platform.

#### System Administrators

In the process of virtual and simulation experiment, the workflows of system administrator include user management, permission management, content management, group management and system maintenance. They are described as following:

1. User management workflow realizes user management functions for system administrator, creates account for learner, tutors and administrators.
2. Course management workflow generates information interaction among courses, learners and tutors.

3. Authority management workflow realizes the system administrator authority management function, that is controlling the pages and functions who can access.
4. Content management workflow realizes the content management function for administrators.
5. Group management workflow realizes the function of group management for system administrators.
6. System maintenance workflow realizes system maintenance functions for system administrator.

#### Educational Administrators

The workflows of educational administrators include course management, making training plan, making semester course plan and opening course audit. They are described as following:

1. Course management workflow realizes the course management function that interacts with the system administrator user management workflow and also interacts with learners to view the course information workflow.
2. Developing training plan workflow realizes the function of educational administrators to develop training plans. They make the training plan, which facilitates the learners to view the training plan and generates information interaction between them.
3. Establishing the term course plan workflow realizes the function of educational administrators in making term course plan. They develop course plans and interact with learners by course selection to generate information.
4. Auditing curriculum provision workflow realizes the function of curriculum provision auditing for educational administrators. They will interact with the workflow of the curriculum provision, the course selection workflow of students and the responsible course workflow of the tutors.

### 4.2.2 Learning and Tutoring

When course plans have been made by administrators, learners and tutors could learn and tutor in the virtual and simulation laboratory with the services of platform.

#### Learners

Workflow of learners includes viewing course information, viewing training plans, selecting courses, viewing course selection results, self-selected experiments, checking in, making experiments, submitting experimental reports and results and viewing grades. They are described as following:

1. Viewing course information workflow realizes the function of learners to view course information. It interacts with the course management workflow of the administrator and the course planning workflow of the tutor.
2. Viewing training plan workflow realizes the function of learners to view training plan. Learners could view and conduct the training plan, or they could negotiate the training plan workflow with the tutor.
3. Selecting Course workflow realizes the function of learners' course selection. It interacts with the semester schedule.
4. Viewing the course selection result workflow realizes the function of learners in order to view the result of course selection. It generates information interactions with administrators' reviewing courses.

5. Self-selected experiments workflow realizes the function of learners' optional experiment. It interacts with the experimental workflow arrangement of tutors.
6. Check-in process workflow realizes the function of learner check-in. It interacts with attendance management workflow of the tutor.
7. Experimental workflow realizes the function of learners to conduct experiments.
8. Submitting experiment report and result workflow realizes the function of learners to submit experiment reports and results. It interacts with the tutor's correction workflow.
9. Viewing grades workflow realizes the function of learners to view the result. It interacts with the posting the grades workflow of tutors.

**Tutors**

Workflow of tutors includes viewing curriculum plan, viewing training plan, viewing own courses, designing the experiment, arranging the experiment, attendance management, reports correcting, posting the grades and inquiring the result statistics. They are described as following:

1. Viewing curriculum plan workflow realizes the function of tutor access to curriculum plan. There is an information interaction between the workflow of the tutor referring to the course plan and the workflow of the student viewing the course information.
2. Viewing training plan workflow realizes the function of tutor to view training plan. It interacts with viewing and conducting the training plan workflow of learners.
3. Viewing own courses workflow realizes the access function of teachers to view own courses. It has an interaction with viewing curriculum plan workflow and the administrator's auditing curriculum provision workflow.
4. Designing experiment workflow realizes the function of tutor to design experiment.
5. Arranging experiment workflow realizes the function of tutor to arrange experiment. It interacts with selecting the experimental workflow of learners.
6. Attendance management workflow realizes the attendance management function of tutors. It interacts with the check-in workflow of students.
7. Reports correcting workflow realizes the function of tutor's correction to report. It has an interaction between submitting the experiment report and view report grades workflow of learners.
8. Posting report grades workflow realizes the function of teachers to publish report grades. It has an interaction with the viewing report grades workflow of students.
9. Inquiring the result statistics workflow realizes the function of tutor to query result statistics.

## 4.3 Construction Decisions

From the above analysis, platform for virtual and simulation experiment involves a variety of roles and has complex functions, and needs meeting the requirements of specified learning strategies, which leads the development of VSE platform to be a complex specified learning management system. So many decisions should be made at first for developing the platform, which includes selecting infrastructure, choosing programming language, determining development framework and combining soft development methods.

### 4.3.1 Selecting Infrastructure

#### Requirements Planning

The first step is to determine the basics of the site. Firstly, the platform for virtual and simulation is a kind of dynamic sites. Secondly, the visits must be estimated. If the platform is only for school internal usage, a single server may satisfy the requirements, otherwise server clusters should be considered. Thirdly, the data volume and whether it will continue to increase rapidly in the future should be taken into consideration.

#### Selection Strategy

The following are some basic strategies for selecting suitable CPU, RAM, storage and physical location to satisfy the requirements.

1. CPU. The virtual and simulation platform contains many dynamic pages, it is recommended to choose CPU with more than 2 cores.
2. RAM. Server could create a larger available cache from larger memories. It is recommended to choose at least 4GB of memory.
3. Disk. Disk is much cheaper than RAM and leaving more space for satisfying the increase of data, thus, is much more recommendable.
4. Bandwidth. The greater the bandwidth of the server has, the faster the access speed the users feel and the more visitors the platform would support. The website application of this kind of website needs at least 1M bandwidth. For large contents or static objects, it is better to store in CDN service.
5. OS. Windows is easier to learn, but occupies more memory. Linux server systems often has no graphic user interface, which leads to save resources.
6. Physical location. Where to locate the server is mainly considered for national local users, or oversea users. Remote disaster recovery is recommended for important applications.
7. Providers. Although many service providers guarantee 7x24 hours service, it still needs to be investigated whether it could be achieved.

Comprehensive consideration should be discussed by both business and technical experts. In practice, cloud service providers tend to offer infrastructure as a service(20), which makes selecting infrastructure be a easier process.

### 4.3.2 Choosing Programming Language

The main programming language to construct the virtual and simulation platform should be evaluated carefully. The development team will be immersed into programming from the beginning to the end, and even the project in maintenance. Programming-language choice will affect the productivity and quality in several ways, shown as Table 4.1(21).

1. Using familiar languages makes programmers be more productive.
2. Working with high-level languages make programmers achieve better productivity and quality than working with lower-level languages, shown as Table 4.1.
3. There are differences in expressing programming concepts among languages.
4. Programmers may be similarly influenced by their languages.
5. Evidence of the effect of programming languages on programmers' thinking is common.

We recommend that large teams should use most commonly used languages in the team or the society even if the ratio is equivalent C code is not high due to high communication costs among members. For small teams, languages with more expression ability and ratio could be considered to create better productive and quality.

| Language | Level Relative to C |
|---|---|
| C | 1 |
| C++ | 2.5 |
| Fortran 95 | 2 |
| Java | 2.5 |
| Perl | 6 |
| Python | 6 |
| Microsoft Visual Basic | 4.5 |

Table 4.1: Ratio of High-Level-Language Statements to Equivalent C Code. A Higher Ratio Means that Each Line of Code in the Language Listed Accomplishes More than Does Each Line of Code in C.

### 4.3.3 Determining Development Framework

The Model-View-Controller(MVC) is an architectural pattern which separates an application into three main logical components: the model, the view and the controller(22). Each of these components is built to handle specific development aspects of an application. MVC is part of the most frequent used industry-standard web development framework to create scalable and extensible projects.

The model corresponds to all the data-related logic which users work with. It could be the representation of data which is being transferred between the view and the controller. It could also be other business logic-related data. The view is used for all the UI of the application. The controllers act as an interface between the model and the view. They process all the business logic and incoming requests, manipulate data using the model and interact with the views to render the final output.

According to the Github's statistics of the number of stars obtained by the MVC development framework corresponding to each programming language as of May 15, 2020, the number of stars obtained by dynamic language (PHP, JavaScript, Ruby, Python) development framework is significantly more than that obtained by static language (Java, C#), as shown in Table 4.2. With the rapid development of mobile Internet, the development and the iteration speed of all kinds of Web applications is getting faster and faster, and the development speed of Web applications is getting more and more attention. MVC framework based on the language is gradually obtaining more stars in the industry. That is because although dynamic languages have lower running efficiency than static languages, they could be interpreted to run, so they are with faster start-up speed, lower initial response time and higher development efficiency.

| Language | Framework | Stars | Owner of Github |
|---|---|---|---|
| Java | Spring | 37.0K | spring-projects |
| C# | ASP.NET | 17.4K | dotnet |
| PHP | Laravel | 59.1K | laravel |
| JavaScript | Express | 48.6K | expressjs |
| Ruby | Rails | 45.6K | rails |
| Python | Django | 49.3K | django |

Table 4.2: Stars Comparison of Open Source MVC Framework

### 4.3.4 Combining Soft Development Methods

Object-Oriented, Aspect-Oriented, Component-based and Model-based are useful development methods to construct a software. Combining different methods may lead to higher production and quality. For example, component-based with domain engineering and model driven method takes more advantage to the fields of virtual and simulation experiments.

#### Domain Engineering

Component Based Software Engineering focuses on a specialized branch of the vast domain of software engineering(23). The number of requirements of virtual and simulation experiment is finite, thus high reusability components can be built from those requirements. It should consist of reusability issues, interaction and integration issues and testing and reliability issues.

#### Model Driven Method

The MDD approach focuses on the construction of a software model(24). It makes to add functions to the software without changing existing codes, but changing the software model. Thus the model makes engineering process much more simple. The model is far more understandable for teams and persons, so collaboration among developers could be much more efficient, which make tests, builds and deployments much faster.

# 4.4 Technology Roadmap

Technology roadmap includes designing a layered architecture, setting up the data Layer, building data access layer, constructing business logic layer and implementing the presentation layer.

## 4.4.1 Designing a Layered Architecture

The layered architecture is one of the most common architectures. It is widely known and used in most MVC frameworks crossing all kinds of programming languages by architects, designers and developers. It can simplify the complexity by dividing the whole platform into layered modules. So it is a natural choice for most kinds of applications. The platform for virtual and simulation of course is consistent with this pattern.

Modules are organized into horizontal layers. The pattern doesn't specify the number and types of layers, but most layered architectures consist of four standard layers: presentation, business, database, data access. In some cases, the business layer is divided into a persistence layer and a pure business layer when repository pattern is used for data persistence. Smaller applications may only have the three layers, while complex applications may contain more layers for making each layer higher cohesion and lower coupling. Each layer has its own specific role and responsibility within the application, and usually not needs to know detail logic in other layers. By classifying modules into different layers with the layered architecture pattern, it is easier to build effective functions with higher efficiency. Thus, developing, testing and maintaining of applications could be simplified with well-designed interfaces among the layers.

## 4.4.2 Setting up the Data Layer

In general, the data layer consists of relational database to store relational data, and file system for storing unstructured data, such as images, documents, etc. If distributed cache is required, NoSQL[1] databases are also popular with the developers.

### Relational Database System

The DB-Engines Ranking ranks database management systems according to their popularity. The ranking is updated monthly, the top 20 popular ones are shown as figure 4.1. Oracle[2], SQL Server[3], MySQL[4] and PostgreSQL[5] are the most commonly used databases. They are all a kind of RDBMS[6]. So developers normally get caught in the comparison among them.

Microsoft SQL Server is relational DBMS by Microsoft, Oracle is relational DBMS by Oracle, they are commercial products. MySQL and PostgreSQL are open and free sources. PostgreSQL and MySQL are recommended because they are strong enough for most cases.

1 https://en.wikipedia.org/wiki/NoSQL

2 http://www.oracle.com/

3 https://www.microsoft.com/zh-cn/sql-server?rtc=1

4 http://www.mysql.com/

5 http://postgresql.org/

6 https://en.wikipedia.org/wiki/Relational database management_system

| Rank | | | DBMS | Database Model | Score | | |
|---|---|---|---|---|---|---|---|
| Jun 2020 | May 2020 | Jun 2019 | | | Jun 2020 | May 2020 | Jun 2019 |
| 1. | 1. | 1. | Oracle | Relational, Multi-model | 1343.59 | -1.85 | +44.37 |
| 2. | 2. | 2. | MySQL | Relational, Multi-model | 1277.89 | -4.75 | +54.26 |
| 3. | 3. | 3. | Microsoft SQL Server | Relational, Multi-model | 1067.31 | -10.99 | -20.45 |
| 4. | 4. | 4. | PostgreSQL | Relational, Multi-model | 522.99 | +8.19 | +46.36 |
| 5. | 5. | 5. | IBM Db2 | Relational, Multi-model | 161.81 | -0.83 | -10.39 |
| 6. | 6. | ↑ 7. | SQLite | Relational | 124.82 | +1.78 | -0.07 |
| 7. | 7. | ↓ 6. | Microsoft Access | Relational | 117.18 | -2.72 | -23.83 |
| 8. | 8. | 8. | MariaDB | Relational, Multi-model | 89.79 | -0.30 | +4.59 |
| 9. | 9. | 9. | Hive | Relational | 78.65 | -2.89 | -0.40 |
| 10. | 10. | 10. | Teradata | Relational, Multi-model | 73.28 | -0.60 | -3.36 |
| 11. | 11. | ↑ 13. | SAP Adaptive Server | Relational | 53.09 | -0.90 | -2.03 |
| 12. | ↑ 13. | 12. | SAP HANA | Relational, Multi-model | 50.82 | +0.29 | -5.56 |
| 13. | ↓ 12. | ↓ 11. | FileMaker | Relational | 50.16 | -0.80 | -7.64 |
| 14. | 14. | 14. | Microsoft Azure SQL Database | Relational, Multi-model | 47.78 | +5.03 | +18.77 |
| 15. | 15. | ↑ 16. | Google BigQuery | Relational | 28.29 | +0.70 | +5.16 |
| 16. | 16. | ↓ 15. | Informix | Relational, Multi-model | 24.38 | +0.54 | -2.44 |
| 17. | ↑ 18. | ↑ 19. | Amazon Redshift | Relational | 21.24 | +0.97 | +0.97 |
| 18. | ↓ 17. | ↓ 17. | Vertica | Relational, Multi-model | 21.03 | +0.28 | -1.52 |
| 19. | 19. | ↓ 18. | Firebird | Relational | 19.90 | -0.10 | -1.98 |
| 20. | ↑ 21. | 20. | Netezza | Relational | 18.38 | +1.02 | -1.88 |

Figure 4.1: DB-Engines

When choosing between MySQL and PostgreSQL, each has its merits on performance[1]. It should not be a factor for most applications. Their salable version are provided for many cloud providers, thus the future growth of application is guaranteed with the techniques. Other features should be considered seriously rather than the performance.

- Postgres is an object-relational database, while MySQL is a purely relational database. Some features like table inheritance and function overloading may make great process in certain applications.
- Postgres is more close to SQL standards. For example the 'group' clause and windows functions are not supported in earlier versions of MySQL.
- Postgres handles concurrency better than MySQL for multi-version concurrency control without read locks, parallel query plans with multiple cores, non-blocking index creating, partial indexes, etc.

Despite all of these powerful advantages, MySQL has earlier accumulated more users, it is simple and enough for many cases especially in website. There are still some small drawbacks when developers decide to use Postgres.

- Despite catching up in recent years, Postgres is still less popular than MySQL, which leads to less tools, developers and database administrators available.
- Postgres occupies more memory when it creates new client connections with process model.
- For some simple and read-heavy functions, Postgres might be a worse choice than MySQL because more powerful features cost more resources.

1 https://developer.okta.com/blog/2019/07/19/mysql-vs-postgres

### NoSQL Database System

NoSQL databases are called Not only SQL to emphasize the fact that they could support SQL-like query languages(25). Relational databases store data as tables, while NoSQL databases organize data as trees or key-vales. Thus data structures in NoSQL databases are far more flexible than tables in relational databases. It makes many operations faster than relational databases. So they could be used in real-time web applications. Redis[1] and MongoDB[2] are the two most widely used NoSQL database systems.

Redis is an open source, in-memory data structure store, used as a database, cache and message broker. It supports data structures such as strings, hashes, lists, sets, sorted sets with range queries, bitmaps, hyperloglogs[3], geospatial indexes with radius queries and streams. Redis has built-in replication, Lua scripting, LRU eviction, transactions and different levels of on-disk persistence, and provides high availability via Redis Sentinel and automatic partitioning with Redis Cluster.

MongoDB is a document-oriented NoSQL database used for high volume data storage[4]. Instead of using tables and rows as the traditional relational databases, MongoDB makes use of collections and documents. Documents consist of key-value pairs which are the basic units of data in MongoDB. Collections contain sets of documents and function which is the equivalent of relational database tables. MongoDB is a database which came into light around the mid-2000s.

### File System

If one server is enough, the local file system is the best choice without any configurations. But for data security or sharing data between servers, Network file system is required. SMB, NFS, and iSCSI are common used network protocols for sharing files. There are differences among SMB vs. NFS vs. iSCSI.[5] NFS protocol offers better performance than the SMB. But if Windows systems are chosen, developer may use SMB as a more natural choice.

## 4.4.3 Building Data Access Layer

CRUD (Create, Read, Update, and Delete) operations are the main functions of most kinds of applications, the virtual and simulation platform is no exception. Separating the data access code from others is indeed a current industry trend, i.e. creating a data access layer, which allows the developers to make database access or code changes without impacting on the rest of codes. Some data access could be reused across applications and databases. With well designed data access layer, it is easy to switch the databases system without affecting other layers. Object relation mapper[6] and the repository pattern are the key techniques.

### Object Relation Mapper

An object-relational mapping (ORM) is a code library which maps the changes of objects to changes of data stored in relational databases tables by generating SQL query from changed object models. It is widely used in all kinds of modern applications. They provide a high-level abstraction of relational databases and enable developers to write

1 https://redis.io/

2 https://www.mongodb.com/

3 https://en.wikipedia.org/wiki/HyperLogLog

4 https://www.mongodb.com/

5 https://www.gigxp.com/smb-vs-nfs-vs-iscsi/

6 https://en.wikipedia.org/wiki/Object-relational_mapping

code of high-level programming languages instead of SQL scripts. So it gets more production and quality in CRUD cases, and speeds up creating basic functions of applications.

#### The Repository Pattern

The repository pattern could simplify the data access layer further. Repositories encapsulate the logic required to access data sources, and could be implemented as classes or packages. They could help encapsulate complicate cases which modify multiple tables to a simple class. The centralization of common data access provides better maintainability and decouples the infrastructure. With Object-Relational Mapper (ORM) like Entity Framework or Hibernate, the codes could be implemented simply with LINQ[1] and other structured query language to strong-typed objects. So developers could pay more attention to the data persistence logic.

### 4.4.4 Constructing Business Logic Layer

Constructing business logic layer is to build the custom rules or implement algorithms which handle data exchange between the other layers and make them well organized. Business layer often defines how a business operates or sets rules on business. Business logic is often described as workflows which are in sequences or steps that specify roles and their functions in detail. So workflow engine plays an important role in the business logic layer.

Business logic is the computational part of the architecture, it is responsible for handling the business logic of the system, communicating between the data access layer and the presentation layer, modeling user-defined processes and returning error messages to the presentation layer when users' actions are not compatible with the rules. The business logic layer contains objects and functions which execute the business functions. The Command pattern, as one the most important designed pattern in object-oriented programming, should be considered as a basic pattern to implement these objects. So common packages are widely used in the business logic layer despite of the specified programming languages. The following are some examples.

1. Workflow engines, such as Activity, are perfect solutions when developers deal with business entities of life cycle management.
2. Reporting engines integrate many advanced reporting features such as advanced grouping, filtration, sorting and conditional formatting.
3. Job Scheduling Library, such as Quartz, could schedule jobs in the background and make long running tasks with higher user experience.

### 4.4.5 Implementing the Presentation Layer

The presentation layer communicates with business logic layer by protocols, such as HTTP, Web-sockets and WebRTC. The four big players in the presentation layer are as follows:

1. Hypertext Markup Language (HTML) is used to create documents which could be rendered by browser and make them functional.
2. Cascading Style Sheets (CSS) is a stylesheet language used to describe the presentation of a document. It describes how elements should be rendered on screen.

1 https://docs.microsoft.com/en-us/dotnet/standard/using-linq

3. JavaScript is a scripting programming language that runs on the web browser to make specific features on the web page functional.
4. Resources. It includes images, audios, videos, 3D models, etc.

Javascript Framework is the core part in building modern applications. Angular[1], React[2] and Vue[3] are the most widely used modern Javascript packages, and build a huge ecology in frontend developing. Vue comes last but get most stars on Github for taking many advantages from other framework and making it easier to understand and easy-to-use. It is a progressive framework for building interactive hypermedia components of user interfaces. The core library is focused on the view layer only, and is easy to pick up and integrate with other libraries or existing projects[4]. It is also perfectly capable of powering sophisticated Single-Page Applications when it is used in combination with modern tooling and supporting libraries. It lets you extend HTML with HTML attributes called directives, directives offers functionality to HTML applications, and provides built-in directives and user defined directives.

Javascript could also have libraries to transfer data with server with synchronous or asynchronous techniques. The protocols are as follows:

1. HTTP (Hypertext Transfer Protocol)[5] is the set of rules for transferring files, such as text, graphic images, sound, video and other multimedia files on the World Wide Web. As soon as a Web user opens their Web browser, the user is indirectly making use of HTTP. HTTP is an application protocol which runs on top of the TCP/IP suite of protocols (the foundation protocols for the Internet).
2. The WebSocket[6] protocol, described in the specification RFC 6455 provides a way to exchange data between browser and server via a persistent connection. The data could be passed in both directions as "packets", without breaking the connection and additional HTTP-requests. WebSocket is especially great for services that requires continuous data exchange, e.g. online games, real-time trading systems and so on.
3. WebRTC[7] could add real-time communication capabilities to your application that works on top of an open standard. It supports video, voice and generic data to be sent among peers, allowing developers to build powerful voice- and video-communication solutions.

## 4.5 Quality Characteristics

Quality is one of the main factors of the success in software development. Both extrinsic and intrinsic characteristics should be considered. They are discussed detailly in Code Complete(21).

### 4.5.1 Extrinsic (For users)

Extrinsic characteristics are highlighted by users.

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1 https://github.com/angular/angular
2 https://github.com/facebook/react
3 https://github.com/vuejs/vue
4 https://vuejs.org/v2/guide/
5 https://www.w3.org/Protocols/
6 https://en.wikipedia.org/wiki/WebSocket
7 https://webrtc.org/

1. Correctness: the extent to which the entire system is affected by specification, design, and implementation errors.
2. Usability: how easy it is for users to learn and use the system.
3. Efficiency: minimal utilization of system resources, including storage and execution time.
4. Reliability: the ability of a system to perform a specific function under certain conditions -- with a long average time between failures.
5. Integrity: the quality of preventing illegal or inappropriate access.
6. Adaptability: the ability of a system to be used without modification in an application or other environment, without having to go through a specific design.
7. Accuracy: the degree of which a system is immune to errors, especially in terms of data output, is a measure of how well the system does its job.
8. Robustness: the ability of a system to continue to perform its functions against invalid inputs or under pressure.

### 4.5.2 Intrinsic (For developers)

Intrinsic characteristics are deliberate for developers.

1. Maintainability: The ability to modify a software system to improve its performance or correct its errors.
2. Flexibility: the ability to adapt systems to different USES or environments without having to design them specifically.
3. Portability: the ability to modify a system intended to run in another environment.
4. Reusability: the ease with which parts of a system can be used for other systems.
5. Readability: the ability to read or understand system source code, especially in detail.
6. Testability: a unit or system which could be easily tested to verify if it meets all requirements.
7. Comprehensibility: The ability to understand an entire system at a level or in detail.

# Chapter 5 Resource Development for Virtual and Simulation Experiment

Learning Resource plays as the core part of the platform of virtual and simulation experiment. Different from traditional learning resources, the resources of virtual and simulation experiment are of immersion, interaction and imagination. Thus resources of virtual and simulation experiment have higher technological threshold and cost of development. In this chapter, the resource development for virtual and simulation experiment will be introduced. Firstly, typical types for virtual and simulation experiment will be discussed with PDR hierarchical model from learner congition and credibility. And then development process of the resources will be explained in detail, including the representation the content with data structures, building 3D model with 3D modeling tool or 3D reconstruction, programming with 3D graphics library and interface, generating resources by intergrated development with 3D engine and publishing the resources to videos, web applications or native applications according to the characteristics of the resources.

## 5.1 Typical Types of Virtual and Simulation Experiments

Experiments are important means of knowing and transforming the world. There are limitations in physical laboratory for distance education. Nowadays virtual and simulation experiments have been developed rapidly.

However, they face many challenges in tutoring and learning, including the losing of immersive feelings, the lack of authenticity in interactions, etc.

From the perspective of learner's perception on virtual experiment, the model of cognitive credibility includes three dimensions: the degree of environment fidelity, the degree of user experiences, and the degree of operation and control credibility. Afterwards, from the credibility degree of virtual experiment perspective, the hierarchical model can divide virtual and simulation experiments into three typical types, which includes three hierarchies of the procedure: procedure-based, data-based, and reality-based(26).

### 5.1.1 Learners Cognition and Credibility Model

The cognition of the learner (operator) to the virtual experiment involves the problems of authenticity, operation credibility and learning experience in the virtual and simulation experiment environment. Therefore, the credibility of virtual experiment needs to be measured from three dimensions that are environmental similarity, control credibility and user experience. Each dimension contains three levels of progression that is a gradual approximation to the cognition of the real experiment.

The degree of environment fidelity refers to the similarity between experiment environment and real environment. It includes the experimental subject and form, attributes of experimental entity, fidelity among objects and between objects and environment in the experimental process. Thus it can give immersive feeling to learners, which lead to immersive learning. An ideal simulation environment should make it difficult for the user to distinguish the virtual and reality. This is helpful to improve the credibility of the virtual experimental environment. From the perspective of environmental fidelity, virtual experiment includes three levels: form, attribute and process.

The degree of operation and control credibility refers to confidence degree of users when they are on the operation and control of the experimental object, including the feedback accuracy of the control object and accuracy of actions in the operation process. From the prospect, virtual and simulation experiments consist of three levels: flow, data and action.

The degree of user experience refers to users' experience of experimental objects and environment. It mainly measure users' feelings when they are "touching" and "using" virtual and simulation experiments. The feelings include perception of vision, hearing, taste and touch, convenience and fidelity of experimental process interaction, and adaptive feedback of different experimental objects or different manipulative behaviors. From the perspective of user experience, virtual and simulation experiment includes three levels: perception, interaction and adaptation.

### 5.1.2 PDR Hierarchical Model for Classification

When the three degrees of environment fidelity, control credibility and user experience are at the same level, virtual and simulation experiments can be classified into three typical types: simulation experiment, exploratory experiment and empirical experiment.

Procedure-based experiments are procedure-based virtual experiments at the first level on the three degrees (form, flow, and perception). Data-based experiments are at the second level on the three degrees (attributes, data, and interactions). It can not only simulate the experimental process, but also display, record, collect and analyze experimental data. Reality-based experiments are at the third level on the three dimensions (process, action and adaptation). As a virtual experiment "close to reality", it not only has the characteristics of the others, but also pays more attention to solving problems based on reality in the state of spatiotemporal separation between participants and subjects.

In terms of the degree of fidelity, the authenticity of the empirical experiment is the highest and the closest to the real experiment, while the authenticity of the simulation experiment is the lowest. As far as experimental learning experience is concerned, empirical experiment is the most concrete and vivid, and process simulation is the most abstract in real situations. The hierarchical relationship of simulation experiment, inquiry experiment and empirical experiment is called PDR hierarchical model of virtual and simulation experiment.

#### Procedure-based Experiment

As simulation of the process, procedure-based experiment is focused on visual, hearing, touch and experience vivid perception of experimental operator. It emphasizes the consistency of virtual and real experiment in the operation flow, the subjects of similar to real instruments and equipment on the form, is mainly used for including biology, chemistry, and demonstrates the general principles of subjects such as physics, pay more attention to steps or process experience, the purpose is to make participants familiar with the operation of the equipment and the use of learning standard operation and process.

#### Data-based Experiment

Data-based experimentation is a virtual experiment for data recording and collection and analysis, emphasizing the naturalness of the interaction and the consistency of the measured data in the actual environment. Exploratory experiments are mainly used to present the properties of special things and experiential discovery of the relationship between things. The purpose is to test the concepts and principles learned in class, to help students master scientific methods and to develop their critical thinking.

#### Reality-based Experiments

Reality-based experiment is a virtual experiment based on solving practical problems under the condition of time and space separation between experimenter and subject. It emphasizes the consistency of the action with the real scene, the fluency of the operation and the adaptability of different subjects during the experiment.

For different typical types of virtual experiments, the process of resource development is similar, which can be divided into several steps.

- Construction of a 3D model. It can be done by using specialized 3D modeling tools, or using 3D reconstruction methods according to different situation.
- Programming with 3D model and building a 3D scene. It can be done by using 3D integrated development environment, i.e. 3D engine.
- Publishing the scene and model. Different resource carrier can be chosen depending on the requirement.

For building and programming with 3D model, representation of 3D model and scene must be introduced first. The platform should support building and customizing the relevant content according to the requirements quickly.

## 5.2 Data Structure of the Virtual Content

Computer graphics is responsible for displaying image data effectively and meaningfully, and it is also used for processing image data received from the physical world. Computer graphics development has a significant impact on many types of media and has revolutionized animation, movies, advertising, video games, and graphic design in general.[1]

### 5.2.1 Representation of 3D Model

3D modeling is the process of developing a mathematical wire frame representation of any three-dimensional object, called a "3D model", via specialized software. Some models can be created automatically or manually, but others must be created manually.

1 http://wikipedia.org/

Multiple approaches can be used for creating 3D models. For accurate and smooth surface, NURBs(27) should be used. Polygonal mesh is more flexible for complex model. Polygonal mesh subdivision is advanced tessellation of polygons, and can build smooth surfaces similar to NURB models. The 3D model can be displayed as a two-dimensional image by 3D rendering. The created model can also be physically created using 3D Printing devices.

#### Polygonal Mesh Modeling

Polygonal modeling is an approach to modeling objects by representing or approximating their surfaces using polygon meshes. It is suitable for real-time applications. A polygon mesh is a set of vertices, edges and surfaces defining the shape of a polyhedral object. The surfaces usually consist of triangles, quadrilaterals, or other simple convex polygons. With simplified rendering, it can also generate concave polygons, or even polygons with holes.

One of the major research area of computer graphics is the study of polygon meshes.Different representations of polygon meshes are needed for different applications and goals. Operations are also supported for performing on meshes, such as boolean logic, smoothing, simplification, and etc. Ray tracing, collision detection, and many other algorithms are developed for making the mesh more natural. If the mesh's edges are rendered without the surface, then it becomes a wire frame model.

#### NURBS

Non-uniform rational basis spline (NURBS) is a mathematical model for generating and representing curves and surfaces.If models and surfaces are defined by mathematical formulae, the NURBS will make the representation with more flexibility and precision.NURBS stands for Non-Uniform Rational B-Spline. It means that NURBS uses rational Bézier curves (a parametric curve used in computer graphics and related fields) and a non-uniform explicitly given knot vector. Therefore, degree, control points, weight, and knot vector are needed to specify a NURBS curve. One-dimensional formations can define curves, and higher-dimensional formations can define surfaces and volumes. They are used for creating 3D objects.

Knots can be added to a existing NURBS dynamically without changing the shape of the curve or surfaces.Thus addition additional control points are provided to control related region of the NURBS curve or surface. It is a much more useful operation than elevating the degree, removing knots, or computing control point positions, etc.

The difficulty of using NURBS is highly relative to the number of control points. With a little practice, developers can use NURBS curves effectively, while NURBS surfaces are much more complicated.Therefore many developers make their effort to simplify and limit the capabilities in their applications.

### 5.2.2 Composition of 3D Scene

The 3D application is to add light, grid data to a 3D scene, and then render the observed scene from a specific camera perspective and draw it onto the screen. 3D scene consists of different objects as follows.

- Coordinate system. All objects are in a scene, so they all have their own coordinates.
- Scene. It is a tree structure that used to represent the entire 3d scene.
- Camera. It is a notion of perspective. In the three-dimensional world, the camera represents the eye of our observer.

- Light. Just like in the real world, if there is no light, we cannot see anything. The light and shadow will be reflected in the visual contrast of light and shade, thus enhancing the three-dimensional sense of objects.
- Mesh. A 3D model Mesh is comprised of a geometry and a material. The geometry determines the geometric shape of the model and the material determines the appearance properties of the model.
- Render. Render a frame of the three-dimensional world seen from the camera's point of view.

### 5.2.3 Rendering 3D Scene to Images

Perspective projection and orthographic projection are mainly two types of projection in computer graphics. So there are two kinds of corresponding cameras.

#### Perspective Camera

Perspective projection is an approximate representation to generate a flat surface from a scene.That creates an image from the scene just as it is seen by the eye. The main feature of perspective projection is that the more farther the subject is from the observer, the smaller of the objects appear. Perspective camera specifies a perspective projection of a 3-D model to a 2-D visual surface in 3D programming, and scale factor is a very import parameter of perspective camera.

#### Orthographic Camera

Orthographic projection uses parallel lines to project a object shape onto a plane. The size of the plane is same regardless of distance of subject from the observer. Orthographic camera specifies a orthographic projection of a 3-D model to a 2-D visual surface in 3D programming. There is not scale factor of orthographic camera, the size of the final image does not matter with the objects which are placed in the world.

## 5.3 Building 3D Model

3D model can be built by construction by 3D modeling tools or reconstruction by algorithms.

### 5.3.1 3D Modeling Tool

The types of 3D modeling tool are now very rich. In addition to the traditional industrial CAD and 3D design software, there are also many specialized design software for various fields.

#### AutoCAD

AutoCAD[1] is computer-aided design (CAD) software that architects, engineers, and construction professionals rely on to create precise 2D and 3D drawings. Draft, annotate, and design 2D geometry and 3D models with solids, surfaces, and mesh objects Automate tasks such as comparing drawings, adding blocks, creating schedules, and more Customize with add-on apps and APIs.

1 https://www.autodesk.com/products/autocad

### 3D Studio Max

3D Studio Max[1], often referred to as 3D Max or 3ds Max for short, is a PC based 3D animation rendering and production software developed by Discreet (later merged by Autodesk). Its predecessor is 3D Studio series software based on DOS operating system. It started to be used in the animation production of computer games, and then it further started to participate in the special effects production of movies and TV films, such as x-men II and the last samurai.

### MAYA

MAYA[2] is a well-known 3d modeling and animation software held by Autodesk. Autodesk Maya can greatly improve the film, television, games, in areas such as development, design, creation of workflow efficiency. While improving the polygon modeling, it also perfects the performance. Multi-threaded support can make full use of the advantage of multi-core processors, while new HLSL shades tools and hardware shading API can greatly enhance the appearance of a new generation of host game, in the role to establish and animation is also more flexible.

### ZBrush

ZBrush[3] is one of the most advanced 3D sculpting and digital painting tools available today for Windows OS. Utilizing proprietary “pixol” technology, it combines the information about objects color, material, and depth information, artists. ZBrush can easily perform incredible feats of design with techniques that are very closely aligned to real-world sculpting.

### SolidWorks

SolidWorks[4] specializes in the development and distribution of mechanical design software Windows products, and provides support services for manufacturers with Internet integration capabilities. The group provides systems that cover the entire product life cycle, including the software systems in design, engineering, manufacturing and product data management.

### Pro/E

Pro/E[5] software provides comprehensive, integrated product development environment. The series software that is included in industrial design and mechanical design and so on a number of functions, includes the management of large assembly, functional simulation, manufacturing, product data management, etc. It has been widely used in electronics, machinery, mould, automobile, aerospace, household appliances and other industries.

### UG

UG[6] contains widely used integrated application suite in the enterprise for a full range of product design, engineering and manufacturing development processes. UG is a powerful solution for industrial designs and styles that

1 https://www.autodesk.com/products/3ds-max/overview
2 https://www.autodesk.com/products/maya/overview
3 https://pixologic.com/zbrush/features/overview/
4 https://www.solidworks.com/
5 https://www.ptc.com/
6 https://www.panacea.lk/nx-ug/

foster creativity and product innovation. With UG modeling, industrial designers are able to quickly build and improve complex product shapes with high-performance mechanical design and drawing capabilities, providing high performance and flexibility for manufacturing design.

### CATIA

CATIA[1] is an important CAD software program that is used in various industries, including the aeronautical industry for designing planes and the automobile industry for designing cars. Some known brands which use this software include Porsche, Renault, Peugeot, Daimler AG, and Volkswagen. The family of products provides product style and appearance design, mechanical design, equipment and systems engineering, management digital prototyping, machining, analysis and simulation.

Other software, such as Cimatron, Rhinocero, Blender, SketchUp, FormZ are also widely used in different industries.

## 5.3.2 3D Reconstruction

With 3D reconstruction algorithms, geometrical structure of a scene can be inferred from a set of images from cameras whose position and internal parameters are assumed to be known or can be estimated from the set of images. From multiple images, 3D information can be partially recovered by solving a pixel-wise correspondence problem. If the surfaces is smooth, the method can get far better results. OpenSfm and Smart3D are softwares for 3D Reconstruction.

### OpenSfm

OpenSfM[2] is a Structure from Motion(28) library written in Python. The library serves as a processing pipeline for reconstructing camera poses and 3D scenes from multiple images. It consists of basic modules for Structure from Motion (feature detection/matching, minimal solvers) with a focus on building a robust and scalable reconstruction pipeline. It also integrates external sensor (e.g. GPS, accelerometer) measurements for geographical alignment and robustness. A JavaScript viewer is provided to preview the models and debug the pipeline.

### ContextCapture

ContextCapture[3] can create 3D models from simple photographs and/or point clouds. A reality mesh is a 3D model of real-world conditions that contains large amounts of triangles and image data. Each digital component can be automatically recognized and/or geospatially referenced, providing an intuitive and immersive way to navigate, find, view, and query your asset information. It can generate spatially-classified and engineering-ready reality meshes at any desired level of accuracy and scale, including an entire city.

1 https://www.3ds.com/

2 https://github.com/mapillary/OpenSfM

3 https://www.bentley.com/en/products/brands/contextcapture

## 5.4 3D Programming

The scene can be interacted with human by programming the 3D model and scene, so that the application makes artist and program get a perfect combination.

### 5.4.1 3D Graphics Library and Interface

Graphics library and interface provide a low level API to programme with graphics. OpenGL, Direct3D, WebGL are most common used.

#### OpenGL

OpenGL[1] is an open-source graphics standard for generating vector graphics in 2D as well as 3D. The cross-language Windows application has numerous functions and is quite powerful in bringing millions of applications to a wide range of operating systems. OpenGL is usually considered an application programming interface (API) that provides users with numerous functions which are used to manipulate and create images and graphics. Moreover, the platform runs on almost all the operating systems, including the Mac OS, Linux, and more.

#### Direct3D

Direct3D[2] is a low-level API for drawing primitives with the rendering pipeline, or for performing parallel operations with the compute shading. It can hide different GPU implementations behind a coherent abstraction. Developers can create applications without going deep into the GPU processors. It is designed as parallel processing and intended to drive a separate graphics-specific processor, so developers can create a bunch of rendering or compute state and then start an operation with hundreds or thousands of parallel processors.

#### WebGL

WebGL[3] is web based on OpenGL API and written in JavaScript. With WebGL, high-level graphics API may be embedded in browsers in the future. WebGL enables web content to use an API based on OpenGL ES 2.0 to perform 2D and 3D rendering in HTML canvas in browsers that support it without the use of plug-ins. WebGL programs consist of control code written in JavaScript and shader code (GLSL) that is executed on a computer's Graphics Processing Unit (GPU). WebGL elements can be mixed with other HTML elements and composited with other parts of the page or page background.

### 5.4.2 Integrated Development with 3D Engine

3D engines provide developers with a framework and a integrated development environment for creating an application. Developers could focus on creating the content of the application itself, that helps developers save time and resources. To use 3D engines to support programming an application, the first step is to make decision of which 3D engine should to used. Just like commanding software development suites, 3D engines contain many different subsystems such as physics engine, audio engine, rendering engine, AI, animation, and etc. Plugins and APIs are also available to customize a 3D engine. Some game engines come with asset libraries to make it even easier to

1 https://opengl.org/

2 https://docs.microsoft.com/en-us/windows/win32/direct3d

3 https://www.khronos.org/webgl/

create an application.

**Unity**

Unity3D[1] is a multi-platform comprehensive game development tool that allows players to easily create interactive content such as 3d video games, architectural visualization and real-time 3d animation. It is a fully integrated professional game engine. Unity takes advantage of interactive graphical development environment as the primary mode of software. The editor can runs on Windows, Linux, Mac OS X, and contents can be distributed to Windows, Mac, Wii, iPhone, WebGL, Windows phone 8, and Android platforms. It is mainly used as creating mobile 3D applictions.

**Unreal Engine**

Unreal ENGINE[2] is one of the most widely licensed game engines in the world, accounting for 80% of the global market for commercial game engines. The Unreal Engine 3 3D Engine features the latest in time trace tracking, HDR lighting, virtual displacement. It is a state-of-the-art real-time engine and editor with photo-realistic rendering, dynamic effects, lifelike animations, and robust data conversion interface, and etc.

**Source Engine**

The Source engine[3] is a 3D game engine for the first-person shooter half-life 2 and licensed to other game developers. As an integration engine, the Source engine provides developers with everything from physical simulation and rendering to server management and user interface design. The engine comes with the Source SDK and Source Film Maker.

# 5.5 Resource Publishing

## 5.5.1 Rendering Static Contents to Videos

Video is the best resource carrier, if the users do not need to interact with the scene. There are many codec standard to render 3D scene with animation to videos, but H.264 is the most commonly used in recent times. It is a highly compressed digital Video codec standard, and is widely used in optical disc, broadcast, and streaming video markets. Static contents can be distributed to all kinds of devices. If render the scene from two cameras with different position, 3D videos can also be producted. It may be useful for theoretical knowledge of virtual and simulation experiments.

## 5.5.2 Lightweight Application with WebGL

Unlike native apps, a single web app can reach out to all kinds of devices without installing. Publishing lightweight application to a web app using WebGL is the optimal choice. With WebGL, Web app can be used to make photo collections or simple animations, even for real-time video processing and rendering when the bandwidth is enough.

1 http://www.unity3d.com/

2 https://www.unrealengine.com/

3 https://developer.valvesoftware.com/wiki/Source

Because web app can be loaded with a single URL, they can be updated and upgraded without sending the installing files to clients. If WebGL is enough for contents of virtual and simulation experiments, then web app will be used to carry the resource.

### 5.5.3 Real-time Interactive Native Application

For some real-time applications, WebGL is often not performing well and needs to be published as an executable application. With native application, all the resources are loaded before starting the main application. Native application could support much better render quality. More interactive devices are also supported in native applications, which lead to higher user experience. For virtual and simulation experiments which need real-time interactions features, native applications are recommended.

# Chapter 6 Tutoring with Virtual and Simulation Experiment

Virtual experiment has positive impacts on students' cognitive load, skills development and motivation(29). In this chapter, tutoring with virtual and simulation experiment will be introduced. Conducting a virtual experiment mainly involves five important steps. The first step is tutor preparation, which includes identifying learning objectives, confirming arrangement of experiment and group work. The second step is learner preparation, which consists of defining research questions and variables, writing a hypothesis and designing experimental treatments. The third step is conducting the experiment, which includes informing learners about the purposes, the procedures, and learning guide. The fourth step is writing the lab report, which includes lab report outline and tips for lab report. The last step is evaluating the results, which consists of formative evaluations, summative evaluations, feedback from learners and weighted score.

## 6.1 Tutor Preparation

### 6.1.1 Identifying Specific Learning Objectives

Tutor preparation can be designed from back to front. Generally the key learning objectives will be established firstly, and then let it drive other decisions. If the experiment results contain data analysis improvement and critical thinking, they should be incorporated into the design of your experiment course.

Before developing a new experiment program, it is essential to take its goals into account. There are a lot of possible targets[1]:

- Foster intuition and deepen understanding of theories.
- Handle basic phenomena.
- Shape critical thinking.
- Improve experimental and data analysis ablities.
- Learn how to operate scientific equipment.
- Both written and oral reporting skills were developed
- Practice the ability of solving problems collaboratively.
- Enhance curiosity and creativity by designing a experiment to test a hypothesis.
- Strengthen comprehension of the role of experimentation in education.

1 https://www.nap.edu/search/?term=Science+Teaching+Reconsideredx=0&y=0

- Verify important rules and regulations.
- Apply newly-learned concepts to new context.
- Learn basic knowledge and persist students' active involvement(30).

### 6.1.2 Confirming Arrangement of Experiment

After identifying learning goals, the tutor should confirm experiment arrangement. It contains three parts: experiment information, theoretical knowledge and pedagogical knowledge.

First, the tutor will grant system permissions to learners, initialize experiment scenarios, and so on. There is a wide range of the experiment information. It mainly includes experimental name, experimental requirements, experimental methods, scoring rules, time schedule, learner, experimental content, lab report requirements, and so on.

Second, in order to clarify the function of each section (background, multimedia, download, etc.), each brief will be provided.

Background: All the basic concepts and theory to finish the experiment will be listed in this section. When the learners conduct the virtual experiment, they can refer to it to save their time. Besides, they can easily review the newly-learned basic knowledge before turning to the next section of virtual experiment. And once they are confused about something, they can return to this certain section.

Multimedia demonstration: With the help of video and audio aids, this section provides support for performing experiments in virtual laboratory. In order to make learners accumulate hands-on experience and conduct experimental operation well, video aids are provided to:

- Show the function of virtual experiment
- Inform the learners about the basic concept
- Demonstrate construction and operating environment of the simulation
- Introduce device used in real laboratory
- Introduce operation procedures and safety notices

In aim to decrease download time and improve video quality, video and audio files are provided in several file formats.

Download section: Learner can get utility programs and simulation software in this section, these applications are freeware or shareware. Learners can find lab sheets to download and follow the procedures as they perform the experiment.Last, the following questions should be taken into consideration when tutors prepare to conduct a virtual experiment[1].

- Familiarity with the equipment.
- Excellent and clear expression of the criteria used in scoring the lab reports.
- Progress monitoring.

1 https://www.washington.edu/teaching/topics/just-for-tas/conducting-labs/

- Potential points of confusion or difficulty when learners perform the experiment.
- Good questions to stimulate learners' thinking and to encourage deeper understanding of the experiment.
- Promotion of group collaboration.

The evaluation of the objectivity of learners' academic performance or the completion of learning objectives are also two essential issues that should be considered. The use of Verbs to evaluate measurable actions (e.g. asses, diagnose, perform) is acceptable while subjective or internal actions are difficult to evaluate (e.g. think, understand).

### 6.1.3 Group Work

Group work is a way to learn from each other by encouraging interactions and involvement, so as to enhance social capability and employability(31). Some experiment projects are of great benefit to group learning. They can be implemented both inside the lab and outside the class, during post-lab discussions or small-group study sessions. Group work not only provides learners with opportunities to learn from each other, but also allows them to corporate in the external world, where most scientific or technical projects involve teamwork.

At the beginning, tutors should divide learners into lab and/or study groups, preferably with 2 to 4 members. Because different experiments require different numbers of organization, the tutor should rearrange the group every once in a while, but no more than 4 people, if you want to encourage each learner to actively participate.

It is a feasible method to ask learners to divide complex projects into different sections and to coordinate individual tasks. If necessary, a lab assistant can assist in coordination. In this way, learners not only take responsibility for part of the project, but also maintain appreciation for the design and concept of the entire project.

## 6.2 Learner Preparation

Learners should be fully prepared before the experiment begins. There are two kinds of preview methods: online and offline. The content of preview includes relevant basic knowledge of the equipment model and experimental principle used in this experiment. The learners' preview effects will be perfectly evaluated after they completing the online preview test, answering preview questions, and forming the preview report. The learner cannot proceed to the next step unless they pass the preview test.

In order to cultivate laboratory-related skills, deep analysis of the research is also a wonderful method. With the access to a large number of articles of review methods, learners can demonstrate presentations about various angles of the methods of some key experiments.

### 6.2.1 Defining Research Question and Variables

Learner should start with an especial question in mind. Learners need to spend abundant time in browsing related research fields to identify knowledge gaps and to find questions.

In order to express it more clearly, we will take one research question example:

**Research question: How does temperature affect soil respiration**

To figure out this question, the learner will raise a series of questions, specially, How the amount of carbon dioxide breathed from the soil is affected by increasing air temperature above the soil surface.

To convert the research question into the hypothesis, learners need to figure out the key variables and make predictions about relations.

First, briefly list the independent and dependent variables. Independent variable is air temperature above the soil. Dependent variable is CO2 produced from soil.

Secondary, he should consider possible confounding variables and methods to control them in the virtual experiment. Confounding variable is soil moisture which also affects respiration meanwhile it decreases as increasing temperature. Learners measure soil moisture and add water to maintain that soil moisture is steady through all treatment plots.

Finally, put these variables into a diagram. Use arrows to reveal the expected relationships between variables and signs to demonstrate the possible direction of the relationships.

Here, we make the following predictions: there is a positive correlation between temperature and soil breathing, and a negative correlation between temperature and soil moisture, and reducing soil moisture will decrease the soil respiration.

## 6.2.2 Writing a Hypothesis

So far, learners have a deep and thorough conceptual understanding of the question, and they should write a testable hypothesis to solve research questions. Null (H0) hypothesis assumes that air temperature is unrelated with soil respiration. Alternate (Ha) hypothesis is that an increase in air temperature leads to an increase in soil respiration.

The next step explains how to design a controlled experiment. In a controlled experiment, researchers should have the following abilities:

- Accurate manipulation of the independent variables.
- Precise quantify of the dependent variables.
- Control of any possible confounding variables.

## 6.2.3 Designing Experimental Treatments

The way learner changes the independent variable will affect the result's external validity. In other words, the extent to which the outcomes can be popularized and applied to the world.

First, how widely to shift independent variable should be decided.

Learner can choose to raise air temperature:

- Level one: just slightly high than the normal range for study region.
- Level two: over a wider range of temperatures to simulate future warming.
- Level three: over an worst range that is beyond any possible natural variation.

Second, how finely to change independent variable should be chosen. This choice is sometimes made by the experimental system, but in most cases he needs to make the decision on his own, which will affect how much learner can deduce from results.

# 6.3 Conducting the Experiment

## 6.3.1 Informing Learners about the Purposes and Procedures

Even though experiments are designed mainly for independent learner's study, most learners will enjoy a brief overview at the start of the conducting.

For example, tutor could:

- Deliver a brief lecture on the relation between the experiment and recent courses and/or confronted issues in the discipline;
- Briefly talk about any other assignment that have given the learners in order to ready them for completing this experiment;
- Clarify any ambiguities in the lab manual;
- Demonstrate detailed procedures at the beginning of course rather than disturb the experiment later;

If both the tutor and learners are full preparation, the tutor will have more time and energy to guide the learners when they conduct the experiment.

## 6.3.2 Guide to Learning

The tutor can check the result of learners with answers and comments, which are timely sent back to the tutor through the Web during performing the laboratory. In this way, learners with problems can be identified and provided with feedback immediately.

A framework for constitute the inquiry cycle contains: orientation phase, conceptualization phase, investigation phase, conclusion phase, and discussion phase(32). To classify the types of guidance that currently exist for different inquiry phases, we use the most recent taxonomy of types of guidance: process constraints, performance dashboard, prompts, heuristics, scaffolds, and direct presentation of information(33).

For example, tutor could:

It would be helpful for learners master the processes of scientific inquiry. The open questions always need time and thought to reply. Thus, the best TAs should avoid asking simple "yes/no" questions or confirmatory questions such as “Did you already know, right?”, just because lead learners can answer them quickly and affirmatively and reduce the possibility of in-depth research and thinking. Instead, here are some kinds of useful questions:

- Ask learners to identify and define a problem in order to solve it;
- Give changes for learners to collect information;
- Allow learners to form a hypothesis;

Tutor should promote the development of learner’s analytical abilities and observational skills. TAs are graduate students, they already have intuitive feeling about what phenomena should be recorded, and usually these feelings are indirect to the question at hand. This sound natural to TA because they have undergone years of training in this field, and learners are first egaging on this training.

Never give outright answers on conception of the experiment. If learners raise, “Why can’t we get this?”, TAs should try to ask a train of questions, it can help them to find answers by themselves, rather than simply explaining the operation for fixing the failure of the experiment.

# 6.4 Writing the Lab Report

## 6.4.1 Lab Report Outline

Learner should write a lab report when the experiment was finished. The tutor will provide the lab report template, mainly which includes title, abstract, purpose, materials, methodology, results, discussion, conclusion, tables, references.

### The Title

The title of the report should state the content of the entire report and experiment. The title should illustrate the context factors which are to be manipulated, the variables which are measured and the specific operation. It would be better to use compact terms and avoid adding any unrelated words.

### The Abstract

Basically, abstract is a summarized edition of the whole report. It would usually be about 250 words. The purpose of the abstract is to comprehend the target , the methods, the outcomes and influence of your experiment quickly. Besides, learner should arrange the content of abstract the same idea as the rest of the report:

- Introduce lab report by a background sentence;
- Propose the objective of report and the hypothesis;
- Make a depiction of the key opinions in methodology;
- Summarize outcomes by mixing quantitative and qualitative methods.

### The Purpose

The next section is the purpose of lab report. Start with the problem that learner are trying to research, and then provide some background details about the problem. These information should be clear, compact and easy to accept.

It should contain a short review of previous research which is related to problem and an explanation which declares how your virtual experiment will focus on making some problems clear or extend the existing knowledge(34). The final sentence should be a announcement of purpose, which would specifically define the main issue that your experiment is about to inquire. In order to build the base of purpose, learner will use different references.

### Materials and methodology

This section would be about how and when learner had done experiment. It should embrace the experimental design, equipment and devices used in the experiment, the methodology used to collect and analyze the data and all other types of control. All the information you write this section must be complete and in full detail so that it can be fully used by anyone who wants to repeat your experiment. Here are some tips for you:

- Use either a passive voice or an active first person voice when making your descriptions.
- Enumerate a reference to all the methodology that you have modified from other sources;
- Make full use of illustrations, pictures, tables and such, according to the need of describing the experimental installed;
- Make a detailed description of the procedures you had changed as compared to the procedures which you had used as a reference.

### Findings

When learner presents the results, he only need to show the observations and the related data, without adding any meaning and analysis.

With the aim of making it easier to understand, learner should make sure to use complete sentences, and figures, tables and such which would assist the results.

- Use both lexical and numerical data, as well as appropriate vocabularies to describe your results;
- Use the past tense to explain your findings;
- Detailed calculations or outcomes are give in appendix.

### Discussion

In this section, it mainly introduce how do discuss findings. You will not only explain the relationship between your experiment and the previous work, but also explain the meaning the results in your perception.

- Give an explanation of the relations which had occurred;
- Discuss the reason for what you did, what is the results and how it is related to the purpose of virtual experiment.
- Compare the results to the existing trends;

- Use some references to supply your interpretations;
- In order to readers can easy to understand the discussion section, it is better that you are usually objective description;
- Declare learner accept or reject the hypothesis had written. Give an explanation what is influence of the finding from your virtual experiment(35).

### Conclusion

This section embraces a short sentence, which restates experiment target, main outcomes and how the virtual experiment contributes to the development of learner.

### Tables and Figures

This section includes tables and figures for presenting data directly. There are a few tips for learner:

- Figures contain a lot of visualization, such as maps, graphs, chart and such;
- Enumerate every table and figure so as to tutor can easily loacte them;
- Tables and figures should have their own title that were used to self-explanatory and can be understand quickly.

### References

This section presents all resources of opinions and facts that learner have used during all experimentation. If learners refer to them, it is helpful for building the connection between existing research and this experiment.

- Presented in the form of a list, which is written on a single page and put on the end;
- Include all the unoriginal information;
- Refer all the research which learner have mentioned.

If learner're making a official lab report, these sections should be includes into the report, no matter science, biology, chemistry, physics or such.

## 6.4.2 Tips for Lab Report

The preparation of an excellent lab report template would require many steps, from the moment when learner plan to do the experiment till finish the experiment[1]. There are a few tips complied to guide learner from start to end.

### The Pre-Lab Report

- The introduction would discuss the problem or experiment as well as relevant theories, which are about to study or perform later. Generally it would no more than 5 sentences;
- Use your own words to summarize report in a short paragraph;

1 https://templatelab.com/lab-report/

- Include a background which would explain the reason you perform the experiment;
- Record the objectives of your experiment, including your plan and expectations;
- Elaborate on and write down some related techniques and methodologies which you are designing to use to reach your goal;
- Remember to remain the introduction focus and short;
- The procedural flowchart of report can be longer than the introduction but no more than one page. An effective flowchart, even without much details, would give the reader a good idea and allow them to fully understand how the experiment is performed ;
- Flowchart would serve as a "roadmap" of the experiment. Compared to a list of specific steps, it is more visual and usually a lot easier to recognize. It should indicate all the steps briefly, in an actionable manner;
- Sentences should be uncomplicated and short. This benefits to really consider about the procedures when you try to summarize them. You'd have to record procedure replace rewriting it in a flowchart format.

### The Responsibility during Lab

Generally, virtual and simulation experiment can record all the process data, such as the independent variables and results in traditional experiments, and even need to record some more detailed data, such as operation time, frequency, etc. It can fully monitor any operation. However, because the recording function of each virtual simulation experiment is different, learners need to manually write down some data which is helpful to complete the lab report.

- To ensure that some information will not be wiped, write down with a pen when collecting and recording data;
- Immediately record data in a place where it will not be lost – such as a notebook or paper filed in a folder. Never write down data on scrap paper that may be thrown away;
- Until you've finished lab report, try not to throw anything out. Because every things may contain information vital to your report;
- Back-up the all results and findings as much as possible. In this way, you won't lose any important information;
- Recording observations is as important as collecting data, results, and findings. When you are going through with the experiment, write down all the observations which you may explain while making your report;
- Write everything down in a recordbook, and then when you are modifying your report, you can use recording to build the content. All the notes you took can help you to recall those crucial details during the experiment and to create your final report.

### The Post-Lab Report

- Start with the raw data collected, and recopy everything in a organized way. Presenting data by tables, graphs or such will make the data readable and easy to understand;
- When calculations are involved, it would be better to show all the formulas for calculations. It cannot only help you make calculations, but also help the readers understand how you've calculated;
- All the work for reaching the final results would be added to conlusion. In this way, you will be able to get accurate results. It's a best practice to recalculate using the formulas so that you are sure of answers;

- You must ensure that all the calculations are correct, as they are an vital part of the report. Making mistakes in this section might reduce report credibility and experimental results and findings;
- The main difference between conclusion and introduction is that the conclusion summarize everything you have done, while the introduction demonstrates everything you are planning to do. Both them should be clear and direct.

To help learner out further, confirm to include the following:

- Briefly restate the methods you had gone through;
- Retell all the results and the findings. It is not necessary to include the raw data, just the key results which are more related to the experiment;
- Explain the meaning of the findings in your opinion. You must comment on the results whether they are good or bad. While keeping the conclusion concise and clear, you can also provide some interpretations;
- Finally, write a conclusion which would provide closure to lab report;
- After completing the report, please check it. Fix errors and check whether all spellings and grammar are correct. If working in a team, make sure more than one of the members of the team would be in charge of checking.

# 6.5 Evaluating the Results

## 6.5.1 Formative Evaluations

Several techniques are used for effective formative evaluation for learning, some of them are as follow: exit ticket, classroom quizzes, directed paraphrasing, one-sentence summary(36).

Participation evaluation refers to writing reports on participation rate, experiment time and frequency. Evaluation content includes: experiment participation rate; time and frequency of use. The ratio of the number of learners who actually participate in the experiment to the number of learners in the course is recorded as the experiment participation rate. The time and frequency that learners use the experiment reflects the difficulty of the experiment and the learners' attitude to some extent.

Interaction evaluation refers to the occurrence of various interactive activities(37). There are two evaluation contents: one is to support various interactive activities, which includes interaction between learners and tutoring resources, experimental tutors and other learners; the other is to provide learners' active participation analysis. When encountering problems in the experiment, learners need to interact with available tutoring resources; learners will actively use the resources and user guides provided by the virtual experiment system to help themselves complete the experiment. The higher the learners' active participation, the higher the popularity of various interactive resources in the experiment, and the greater the difficulty of the experiment.

### 6.5.2 Summative Evaluations

Tutor may be asked to evaluate following aspects of experiment performance, including:

- Learners' preparation for the experiment;
- Learners' ability to operate equipment in the experiment;
- Learners' comprehending of the lab procedures;
- Evaluate whether many learners understood key concepts;
- Assess whether learners draw rational conclusions from the collected data[1] ;
- Assess the probability of success for tutor and the learners in the lab. Ask learners how they experience the lab (e.g., key points, challenges) and pay attention to any feedback that can provide information and improvements to the next experiment.

A pretest, a posttest and a lot of sheets were used for examining the learning results of the learners(38). Provide single-choice, multiple-choice and true/false quiz. The purpose of this is to allow learners to review what they have learned in the experiment. After completing the quiz, an analysis of the quiz result will be displayed on the screen. This analysis can provide response to learners and the tutors.

### 6.5.3 Effective Feedback from Learner

A good experimental environment can effectively improve the learner's experimental experience, and the evaluation of the experimental environment can help discover the defects or deficiencies of the virtual experimental system and related resources.

After each experiment, your lab schedule should include time for the tutor and/or TA to review the results of the exercises in the class. It is essential to push learners check their conclusions and understand the results related to the course theories. Class discussions will also enable you to identify any problems in the lab procedures so that tutor can improve them in the next session[2].

Questionnaire surveys and focus group interviews can fully collect learners' evaluation of the good and bad of the virtual experimental tutoring environment, and feedback on problems.

### 6.5.4 Calculating the Weighted Score

The learner's score consists of preparation assessment, formative evaluation and summary evaluation. The tutor assigns different weights to each part.

Note that the Family Educational Rights and Privacy Act (FERPA) requires TAs and tutors to keep the learners' grade information confidential within their tutoring team(39).

1 https://cft.vanderbilt.edu/guides-sub-pages/lab-classes/

2 https://teachingcommons.stanford.edu/resources/teaching-resources/teaching-strategies/laboratory-teaching-guidelines

# Chapter 7 Project Evaluation of Virtual and Simulation Experiment

This chapter reviews the project evaluation of Virtual and Simulation Experiment. The first section is the evaluation of learning resources, including experimental design and auxiliary learning resources. The second section is the evaluation of experimental system, including credibility, availability, stability, and convenience. The third section is learning evaluation, including tutor preparation, learner preparation, conducting experiments, writing lab reports, and evaluating the results. The last section is the measurement and testing of cognitive credibility, including environment fidelity, user experiences, and operation credibility.

## 7.1 Evaluation of the Experimental Resources

### 7.1.1 Design of Experiments

Type of experiments: reasonable distribution of different types of experiments in the course. Evaluation content includes meeting the needs of learners of different levels, and a reasonable proportion of various types of experiments. Experiment types include procedure-based experiments, data-based experiments and reality-based experiments. The reasonable allocation of various types of experiments depends on the tutoring objectives and experimental content.

Design of typical experiment: the design of typical experimental cases commonly used in experimental tutoring[1]. The evaluation content includes the realization of experimental tutoring objectives, meeting the characteristics of virtual experiments and easy access to the preset experimental environment. It is necessary to provide enough typical experimental cases for the tutor to choose. Typical experimental scenarios include virtual experiment objectives, requirements, preset experiment environment and evaluation rules. The preset experiment environment mainly sets the simulation resources and corresponding parameters required for typical experiments. Typical experiments can be saved independently of the system for continuous supplementation and modification.

### 7.1.2 Learning Resources

Experiment guide: various forms of guides used to design typical experiments. The evaluation content includes complete basic elements, scientific rationale rationale and novelty. The experiment guide includes the title, background, required materials and devices, experiment purpose, experiment principles and theoretical knowledge, experiment procedures, experiment phenomena and results, etc. The scientific rationale of the experiment guide is concerned with the correct theory, strict logic, experimental operation, and user-friendly language. The novelty of the experiment guide is mainly determined by the papers and other academic achievements. The experiment

1 http://c.gb688.cn/bzgk/gb/showGb?type=online&hcno=69DC5E3A119BDA807BD717F28FBE681E

guide can be presented in digital form to facilitate online help.

Knowledge base: relevant experimental knowledge base for experiment content, which aims to provide learners with knowledge introduction and question answering at any time during the experiment. The evaluation content includes scientific, strict and error-free content, classified management, diverse forms, rich content and resources. The content forms in the knowledge base include media materials (generally divided into five categories: text, image, audio, video, and animation), courseware, resource catalog indexes, and online courses. The content of the knowledge base includes but is not limited to experimental concepts and theoretical knowledge, experimental principles, literature and cases, algorithms, questions and answers, and experimental skills. Sufficient experimental knowledge resources can provide learners with good guidance and user experience.

# 7.2 Evaluation of the Experimental System

## 7.2.1 Credibility and Availability

Simulation credibility: the similarity between the simulation system and the prototype system determines the degree to which the simulation system adapts to the simulation purpose(40). Its basic attribute is purpose relevance, so the credibility requirements are also closely related to specific simulation applications. Whether the final result of virtual simulation system can be ued in the expected application will directly affect the subsequent series of applications or the decision-making process based on the virtual simulation result.

Results usability: it can accurately evaluate all elements of the experimental process, objectively record all experimental operations and corresponding experimental results, and support the evaluation and evaluation functions such as error correction guidance, experimental quality and progress ranking, and comprehensive experimental assessment and evaluation(41). To ensure the correctness and credibility of virtual simulation, the final simulation results entail practical application value and significance. The function of experimental teaching, students' free practice and comprehensive objective assessment is complete.

## 7.2.2 Stability and Convenience

Operating environment: a complete and specific description of the basic hardware requirements, network configuration and supporting software names and versions for the operation of the experimental system. The evaluation content includes detailed instructions on the hardware requirements, network configuration and software version required for the virtual experiment operation, and provides a URL for downloading the required software. There are two ways to describe the requirements of the operating environment. One is to create special pages to explain the operating environment requirements in the online course. The other is to list all the requirements in the product manual.

Installation and uninstallation: install the server and client of virtual experiment system. The main evaluation content is whether the loading and unloading process is simple and easy to operate. It should be installed directly on the server side through packaging. If you need to install client software, you should consider browser compatibility and provide corresponding guidance.

Reliability: a certain degree of stability and reliability that the virtual experiment system should achieve. It can be evaluated from two aspects: whether learners can use lower hardware and software configurations to run; and whether a large number of learners can run at the same time. To perfect the virtual experimental tutoring system , it is necessary to improve the reliability under the condition of low-cost databases, middle-ware and WEB application servers. It is recommended to use open source software.

Compatibility: the ability to be deployed on multiple common software platforms of the virtual experiment system. The main evaluation content is that the client supports multiple terminals. The server-side operating system supports at least Linux/Unixs and Windows. The client browser supports mainstream browsers, such as IE, Firefox, Chrome, etc.

Openness: the ability to output various valuable data from the virtual experiment system and exchange virtual experiment resources with other platforms. The main content of the evaluation is the ability to output evaluation data, learners' learning records, tutor work records and other data. Usually use JSON or XML as the file format for data output.

# 7.3 Assessment for Learning

## 7.3.1 Tutor Preparation

Tutor Preparation: experiment design and arrangement according to tutoring objectives. The main evaluation content includes complete basic elements, reasonable arrangements, open system permissions for learners, and initializing experiment scenarios. The content evaluation mainly includes: experiment name, experiment requirements, experiment methods, scoring rules, time schedule, experiment tutor, learner, experiment content, experiment report requirements, etc. A reasonable experiment arrangement depends on whether the experiment is suitable for the experimental subjects, whether the time and progress of the experiment are appropriate, etc.

## 7.3.2 Learner Preparation

Learner Preparation: the final step of preparation before performing the experiment. The evaluation content includes abundant preview materials and the ability to generate preview reports or evaluate the effects of previews. There are two kinds of preview methods: online and offline. The preview includes the relevant basic knowledge of the equipment model and experimental principles used in this experiment. Through the online preview test, answering the preview questions, and forming the preview report, the learners' preview effects are evaluated. Only by passing the preview test, can the learner proceed to the next step.

## 7.3.3 Experiment Procedure

Experiment Procedure: the process of experimenting on the system. The main evaluation content is the ability that the learners can conduct experiments according to the experimental guidance documents; that repeatedly enter the virtual laboratory and continuously modify the experiment results before the end of the experiment time. The learner moves the virtual equipment and materials needed for the experiment to the virtual experiment table, manipulates the experiment object, observes the reaction of the experiment object, and analyzes the experimental phenomenon. During the experiment, learners are allowed to engage in inquiry-based interaction, and the experiment system itself has a fault-tolerant design. The experiment system records the learners' operations and results, and scores them. Learners can allocate time and energy to conduct experiments based on his/her own time, knowledge background and ability to complete tasks. When learners encounters a problem, they can turn to group discussion or online question answered by the tutor.

### 7.3.4 Lab Report

Lab Report: an experiment report written and submitted after the experiment. The evaluation content includes providing experimental report requirements and report templates, so that learners can repeatedly enter the virtual laboratory and continuously modify the experiment results before the end of the experiment report and the completeness. Learners should write an experimental report after completing the experiment. According to the experiment report template provided by the tutor, the preparation of the experiment report mainly includes the experiment name, purpose, materials, methods, data, results, analysis, conclusions, charts and references. The complete performance of the experiment report can promote the learner's mastery of experiment knowledge and related ideas, reflecting the experiment process and the results of the learner and the experimental ideas(42). The experiment report submission system should be easy for learners to fill in.

## 7.4 Cognitive Credibility Assessment

### 7.4.1 Degree of Environment Fidelity

It refers to the fidelity of the virtual experimental environment and the real environment(26). In order to give learners a sense of immersive learning, it usually includes the shape of the experiment object and the environment configuration, the attributes of the experiment object entity, the fidelity of the space-time relationship between the objects and between the objects and the environment during the experimental process. The ideal simulation environment should make it difficult for users to distinguish the false from the true. Improving the fidelity of virtual experiment environment is helpful to improve the credibility of the virtual experiment. In terms of environment fidelity, virtual experiment includes three levels: shape, attribute and process.

### 7.4.2 Degree of User Experiences

It refers to the user's trust in the operation and control of the experimental object, including the operation process, the accuracy of feedback information or data, and the accuracy of action.In terms of user's experience, virtual experiment includes three levels: perception, interaction and adaptation.

### 7.4.3 Degree of Operation Credibility

It refers to the user's experience of the experimental object and environment(26). It mainly measures the user's experience of "contact" and "use" virtual experiments, including the perception of vision, hearing, taste and touch, the convenience and fidelity of interaction during the experimental process, and the adaptive feedback to different experimental objects or different control behaviors. In terms of operation fidelity, the virtual experiment includes three levels: flow, data and action.

# Chapter 8 Leading Technology Breakthroughs in Virtual Reality

In this section, we will show you the latest technology for virtual and simulation lab.

## 8.1 Virtual Reality Extension via Digital Holography

Augmented reality (AR) is a technology that can layer digital elements into real-time views for user interaction. Such technology can be applied in an application on a mobile device.

As a computer-generated simulation, virtual reality (VR) recreates real-life scenarios. It shuts down the real world. Users are immersed in simulated reality, usually as a result of stimulation in their visual and auditory sense.

Mixed reality (MR) is the latest development of such technology, which combines the experience of AR and VR.

A Hologram is a kind of three-dimensional projection created by laser and light, which exists freely in space. The projected light can produce a bright, immersive three-dimensional image. People from different angles are allowed to view the image in their own perspectives at the same time.

A Hologram is the physical record of interference pattern. It uses diffraction to reconstruct the three-dimensional light field. The generated image, as a result, retains the depth, parallax and other characteristics of the original scene. And the science and practice of producing holograms is called holography.

A hologram is not an image formed by a lens. Instead, it is a photographic record of a light field(43). When viewed under diffuse ambient light, the holographic medium, namely that is the object generated by a holographic process, which is normally unintelligible. It encodes the light field as an interference pattern of changes in the opacity, density or surface profile of the photographic medium. That is to say, image seen from different angles means objects viewed from similar perspectives. Meaning that holograms are more than producing illusion of depth, but genuine three-dimensional images.

## 8.2 Edge Computing Enhancement for Virtual Reality

Edge computing is a distributed information technology (IT) architecture. In this architecture, the processing of client data should be at the periphery of the network, as close to the data source as possible. Mobile computing, the reduction of the cost of computer components and the huge number of networked devices in the Internet of things (IOT) have promoted the development of edge computing. According to difference in implementation, time-sensitive data in an edge computing architecture can be processed either at the original point by an intelligent device or transmitted to an intermediate server in a location close to the client geographically. According to difference in implementation, time-sensitive data in an edge computing architecture can be processed either at the original point by an intelligent device or transmitted to an intermediate server in a location close to the client geographically. While Data with low time sensitivity is sent to the cloud for historical analysis, big data analysis and long-term storage[1]. VR Edge computing provides services in the background of decreasing cost of network and application latency. Large-scale resources are provided by centralized data centers or hyperscale cloud provider models and via economies of scale, advantages are gained. Parties share capacity, critical infrastructure, applications, cloud services, staff, and peering in one location. This model will be enhanced by adding VR EDCs (VR Edge Data Centers) to support application requirements that cannot be supported over long network links from centralized DCs. This will overcome barriers such as communication latency and long-distance transmissions costs and will make it possible to support IoT and many of the next generation low-latency technologies. It is important to keep in mind that VR EDCs relocate the geographic extent of the network and computing infrastructure; it is complementary to the current computing design and network infrastructure. It works as a complement to the current computing design and network infrastructure. The edge as well as the core form a holistic infrastructure where the demands and requisites of applications including latency, performance, security and cost determine the location of the resources supporting them.

## 8.3 AI-Powered Virtual Reality

Artificial intelligence, or to be more accurate, machines and deep learning includes algorithms and statistical models that can carry out tasks in a situation where there are no explicit instructions.Machine learning models learn patterns and correlations from training data presented to them, so that they may achieve their goals. These models are the engines set inside of things like predictive keyboards and intelligent photo organizers. With the emergence virtual reality (VR) — fueled by artificial intelligence (AI) — the boundaries of the digital world are moving beyond screens and into the free-flowing, multisensory 3D world. There are some specific ways that AI will make virtual reality (VR) even more real(44).

Artificial intelligence requires machines to perform so-called “smart tasks” and make independent decisions. With the passage of time and the increasing complexity of algorithms, machine learning enables machines to improve themselves. And ways to apply Artificial intelligence together with Virtual Reality are quite various.

1. The fact that VR / AR, along with artificial intelligence have the potential to/are able to cultivate the next generation of professionals who devote themselves to life-threatening and responsible work, such as doctors, factory workers, firefighters, pilots and so on, is incredible. The same kind of solution is also used for doctors. With the application of VR technology, they are able to experience countless virtual scenarios without endangering a single person’s life. Powered by AI, Virtual Reality can also be applied to firefighter teams that experience terrible situations, pilots who take aircrafts back to safety shelters, or emergency medical teams (EMT) that save lives of people who encounter traffic accidents and natural disasters.

2. Danger Alerts: AI has a lot of significant advantages, among these, the ability to make complex decisions has been applied in the national defense industry. The AR military system based on AI can be operated before any weapon is used. Therefore, by comparing with the system archives, a large number of simulations can be tested in order to search for the best military strategy. The continuous progress of technology draws a picture of future battlefield. For instance, ARC4 connects to the military satellites and UAVs, and highlights hazards and

1 https://searchdatacenter.techtarget.com/definition/edge-computing

threats in AR mode.

3. Mapping of Physical Environment: Similar to the training and maintenance-oriented high-quality CAD models, to meet other needs of end-users, companies invite them to try out the mapped physical environment, supposing that they select different kinds of furniture before purchasing, or indulge in AR retail shopping experience.

4. In-Depth, Sensitive Mapping: The future is bright. The reason is that we keep expanding frontiers by examining every possible facet of existing technology. We can both map the walls inside the buildings and furniture, and see through the internal organs of patients who need surgery. We're standing on the threshold of the world, or precisely speaking, a surgical ward where we can see our main organs with a headset. These insights and automatic depth perception with fine tuning will still be deeply embedded in these devices. AI becomes an indispensable part of sports competition, because it can deal with a large number of calculations and data sets

5. Boost Rendering in VR: Facebook has exploited an approach. This AI-assisted approach can super-sample real-time rendered content, which has the possibility to become an indispensable part of future high-resolution VR headsets. This, combined with a number of technologies such as foveated rendering, may bring the generational leap developers are looking for, and truly give VR games an undeniable edge in the visual department. VR games are often maligned for their lower-quality graphics, something will hopefully soon be an anachronism as we approach an era of photorealistic virtual reality.

## 8.4 5G as a Boost for Virtual Reality

5G, namely the fifth generation of mobile network, is a new global wireless standard after 1G, 2G, 3G and 4G network. 5G makes a new kind of network possible, one which aims at connecting practically all people and all things-including machines, objects and devices, together. 5G wireless technology is supposed to provide more users with increased multi-Gbps peak data speed, lower latency, more reliability, huge network capacity, better availability as well as a more unified user experience. Higher performance and improved efficiency empower new user experiences and connects new industries(45).

There are several benefits with 5G application in virtual simulation field.

1. Higher definition VR video screen. 5G is going to bring a wider range of radio channels, carrier aggregation and all. This will meet the high demand of network for information. In comparison with 4G, 5G possesses higher bandwidth and spectrum efficiency, which is critical to provide HD video and other content and along with 360-degree video.

2. Richer situational experience. 5G higher network density will promote the development of the Internet of things and smart city. With the increase of network density, 5G technology will help with the development of IoT and smart city. On this basis, VR technology will make use of these technologies as part of the sensor network to create a more abundant and more situational experience.

3. Lower latency. In theory, 5G network will cut down the defer to as short as 15ms, that is to say the vertigo of VR interactive application can be perfectly removed, the high-fidelity content can be clearer. Meanwhile, the interaction can be more seamless and fast.

4. Lower energy consumption. At present, watching videos or movies consumes a large number of batteries, Unfortunately long-term use will affect the life span of batteries. 5G can improve energy efficiency and reduce battery consumption. With 5G, energy will be more efficiently used and battery consumption will be reduced.

Scenes:

1. Classroom teaching. In the educational scene, virtual reality technology can visualize and visualize the abstract learning content through natural interaction, provide students with immersive learning experience that traditional teaching materials can not achieve, improve students' initiative to acquire knowledge, and achieve higher knowledge retention.

2. Scientific experiment. In teaching, many expensive experimental and training equipment cannot be popularized because of the price limit. By using virtual reality technology and building virtual laboratory on multimedia computer, learners are able to enter the virtual laboratory VLAB and operate virtual instruments in real time. This kind of experiment does not expend equipment, is not restricted by external conditions, for example,the site. One of the advantages of VR laboratory is that it is definitely by all means safe, which will not cause personal injuries as a result of errors in operation.

3. Distance learning. In the long-distance teaching, some teaching experiments and courses that should be set up cannot be carried out because of the reasons of experimental equipment, experimental site, teaching funds and so on. Using virtual reality technology can make up for these deficiencies. Students can do all kinds of experiments without leaving home, but still can get the equal experience as authentic experiments, so as to gain abundant perceptual knowledge and deeper understanding of teaching content.

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