International Journal of Distance Education Technologies
Volume 21 • Issue 1

Exploration on Construction of Mobile Communication Experimental Teaching Based on Virtual-Real Combination

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ABSTRACT

Aimed to adapt the experimental teaching to keeping up with the actual application of the experimental scene, an experimental teaching based on virtual-real combination for mobile communication was proposed in this article, which realized the collaborative mode of combining online virtual operations and real operations. The virtual experiments were complementary to real experiment operation and on-the-spot experience through sharing virtual software, instruments and equipment and remote equipment control with automatic logging for experimenter's data contained knowledge learning, experimental operation process and experimental results so as to evaluate the experiment. Compared with regular sessions, the degree of curriculum achievement in experimental class has improved significantly and the distribution of scores was more reasonable according to tracking the whole process of students. The system with virtual-real combination enriches the practical strategies and improves the quality of mobile communication experiment studying effectively.

KEYWORDS

Achievement Evaluation, Experimental Teaching, Mobile Communication, Teaching Reform, Virtual-real Combination

1. INTRODUCTION

With the rapid development of mobile communication technology, the demand for talents is growing and its requirements are also getting higher and higher. Mobile communication is a major course of communication and electronic information, which has been attached great importance by higher school.

DOI: 10.4018/IJDET.323565

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But the wide range and many abstract concepts were involved in the course of mobile communication. As an important supplement, experimental courses can well make up for the shortcomings of theoretical study (Xu et al., 2018). The existing experimental environment plays an important role in mobile communication studies. At present, most mobile communication experiments in colleges are practiced by combining hardware test boxes with oscilloscopes, which contained several basic principles of wireless communication. However, it was difficult to keep up with the progress of mobile communication technology for the rapid iteration. Students can only observe limited waveforms and data through simple hardware wiring and oscilloscope debugging, instead of knowing the specific circuit composition and parameter settings inside the system. In addition, it is difficult to open to students all day and to maintain experimental equipment subsequently for the expensive cost.

The experimental course of mobile communication is an important part of training students' practical engineering abilities, which is beneficial to laying a foundation for future mobile communication-related practical work for students by understanding and mastering the knowledge and skills of mobile communication technology fully (Gao & He, 2021). However, there are many problems in the traditional experimental teaching of mobile communication course. Firstly, it is difficult to understand for experimenters because of relatively new theories containing some mathematical formulas in mobile communication course. The system experiments were insufficient since the teaching time was cut down. Secondly, most communication systems were updated quickly, and the actual system construction experiments were expensive. Many new generation mobile communication experiments cannot be opened in most ordinary universities because of the limitation of hardware funds. Thirdly, many mobile communication experiments in universities were a simple verification on the experimental box according to the experimental instructions. Students hardly understand the knowledge involving the whole process. It is difficult to expand students' innovative thinking and improve the teaching effect of mobile communication course. It is practicable to construct a virtual environment to complete experiments of mobile communication courses (Bayram & Caliskan, 2019). Some virtual simulation experiments do not sufficiently simulate the experimental parameters, which makes the experimental effect far from the real situation. Generally, some theoretical verifications were not emphasized in the course of virtual simulation, which led to a neglect to understand theoretical knowledge deeply.

The introduction of virtual reality technology into experimental teaching of mobile communication would be beneficial to expanding the traditional teaching model, enriching the teaching content of the mobile communication course, and improving students' learning interest. At the same time, it would stimulate students' learning enthusiasm, enable students to think deeply about the engineering principles and algorithms. By this way, students even may design and improve some systems' functions independently, improve students' innovative thinking, and thus improve the teaching effect of the mobile communication course (Cavanaugh et al., 2023; Degli et al., 2019). In order to cultivate students to better adapt to the high standard needs of society, a construction and management of mobile communication experimental study system based on virtual-real combination was improved to promote the integration of information technology and experimental study and further deepening of mobile communication practical study. By expanding experimental study in multiple dimensions and creating realistic and interactive experimental scenes, students can intuitively recognize and understand the relative theory and knowledge of mobile communication technology so as to enhance students' practical ability and innovation ability and achieve the goal of cultivating communication talents urgently needed by the society. It is important to apply the experimental study method of combination of virtual and real to the curriculum of mobile communication experimental study for the students in university especially in the post epidemic era.

It was an effective way to improve experimental efficiency and equipment utilization through construction of communication experiment based on virtual-real combination, which would contribute to mastering theoretical knowledge deeply with a perceptual understanding of physical equipment. At present, it is rare for the application of the construction of mobile communication experiment teaching based on virtual-real combination. Therefore, a system to conduct experiments for mobile communication based on virtual-real combination was constructed in this paper. The key contributions of this paper were presented as follows:

(i) Construction of a mobile communication experiment teaching based on virtual-real combination.
(ii) Effect evaluation for the mobile communication experimental system applied in professional teaching.

2. BACKGROUND OF THE STUDY

2.1 Virtual Reality Technology

Virtual reality (VR) was a simulation technology involving a collection of simulation technology, computer graphics, human-computer interface technology, multimedia technology, sensor technology, network technology and other technologies (Chavez & Bayona, 2018). The new technology involving simulation and computer was combined with computer technology, multimedia technology, image processing technology, simulation technology and so on. Virtual reality technology mainly consists of virtual reality, virtual reality and high-performance computer processing technology (Jayanthi & Ramesh, 2018). The application of these key technologies could make the virtual space that created by virtual reality technology more realistic, and the user's immersion and interaction better.

The technology of virtual simulation could be used to carry out experimental teaching, which would expand the teaching content and experimental teaching space (Merchant et al., 2014). Experimental teaching based on virtual simulation can reproduce scientific principles in an intuitive and visual way and enhance students' initiatives in experimental process, by which students' ability can be improved effectively to grasp the relative knowledge and analyze problems (Li et al., 2021).

2.1 Research Status

The wide range and lots of abstractive concepts were involved in the course of mobile communication. It is irreplaceable in teaching of mobile communication for cultivating students' innovative talents, realistic scientific attitude, independent practical ability and innovative awareness (Neustock et al., 2018). The traditional experimental box with PC could not reproduce the real situation for mobile communication project as well as the disadvantage of expensive instruments, which could not contribute to understanding of abstract knowledge. In order to meet vocational demand for high-quality talents, it was necessary to promote the deep integration of information technology and higher education experimental teaching (Chen et al., 2021; Nie et al., 2021). Nowadays, virtual experiments were applied in education and developed rapidly. There were lots of explorations and applications on virtual-reality technology in practical teaching successively in a considerable number of colleges and universities at home and abroad.

There were several experimental teaching models based on virtual simulations that were applied in a considerable number of foreign universities. A graphical user operation platform with Lab View has constructed as one of the Internet tools based on remote oscilloscope experiments and pressure experiments when conducting signal processing and data analysis at National University in Singapore (Luse et al., 2021). Similar virtual experimental platforms include the virtual working platform for electronic instruments of the Department of Electronics of the University of Spain and the remote virtual education laboratory of the University of Parvado in Italy (Gatica et al., 2017). The virtual instrument system has become one of the compulsory courses for students majoring in science and engineering in American (Cheon et al., 2020).

Similarly, many explorations on practical teaching with virtual reality technology were also successively carried out in colleges or universities at home. A virtual laboratory of telecommunication network focusing on demonstrating experiments was designed in Beijing University of Posts and Telecommunications and

Jishou University, which can only complete some given experiments (Radianti et al., 2020; Tsai et al., 2019). The experiments about curriculum of communication principle were developed by the team of Central South University (Wu & Han, 2022). A mobile station construction in communication laboratory was built based on real devices, which used to plan network, optimize performance, design algorithm, simulate communication, develop, test and research in the School of Electronics and Information Engineering in Lanzhou Jiaotong University (Ding et al., 2020). The utilization rate of equipment was improved greatly in a mobile communication laboratory based on 5G in communication engineering department of Harbin Engineering University, which was applied to conduct LTE service configuration, router configuration and other experiments and also serves as a training base for enterprises (Chen et al., 2021; Zhou et al., 2022). Aimed the characteristics of electronic information specialty of Beijing University of Posts and Telecommunications, an improved remote virtual experiment platform was developed involving analog electronic measurement, digital electronic measurement, microwave experiment and antenna test (Wu, et al., 2022). Based on the flexibility and configuration architecture of remote laboratories with automatic control, a virtual-reality combination experimental platform with controllable devices including industrial network routers and programmable logic controllers was introduced (Yang et al., 2019; Li et al., 2022). A remote laboratory based on virtual-real combination was proposed to model on various roles and interact between users and remote laboratories by using virtual experiments and physical laboratory simultaneously (Zhao et al., 2021). There was a virtual-reality combination laboratory with graphical user interface based on B/S architecture, by which students can control the components of the experiment, reserve the experiment, and observe the real-time running state of the equipment by controlling the camera (Zheng et al., 2021; Zhou & Wu, 2018).

Virtual simulation experiment teaching has played an important role in the experiment teaching of mobile communication course in many universities, which could also acquire corresponding results as similar as real experiments. It represented many advantages over real experiments as following.

(1) It could provide students a convenient working environment without the limitations of time and space.
(2) It could provide experimental services for many students rather than regular maintenance. So, the cost of construction management and maintenance was lower than the real experiment equipment in laboratory.
(3) There is no physical object and no damage in the virtual experiment.
(4) Resources about the experiments of mobile communication could be shared by different regions.
(5) Students' learning interests could be stimulated under the experimental teaching mode.

However, some effects of experiments with virtual simulation were far from that in real laboratory because some experimental parameters were not simulated sufficiently in virtual environment. Some scenes and operation steps for experiments of theoretical verifications in laboratory were simulated simply without considering the purpose of deepening the understanding of theoretical knowledge for students. Virtual simulation experiments emphasized on experimental operations rather than on realistic reproduction of experimental scenes corresponding to theoretical knowledge.

The concept of "realistic experiment" was put forward for those problems existing in some current virtual simulation experiments, in which the experimental situation and tasks were designed according to the complexity of the real world, rather than deliberately simplify (Yıldırım et al., 2020). How to realize the reality experiment is an urgent problem for online education. Specifically, online reality experiment refers to that the students accessed remote experimental equipment and received the experimental results processed in real experimental equipment by network. Compared with the virtual simulation experiment, the online reality experiment was the same as the physical experiment, which was more realistic and closer to the engineering practice (Zheng, et al. 2020; Guan et al., 2021). The operation of the experimental could be realized through remote call without the need for another virtual simulation of the experimental operation (Ferri et al., 2020). Students could also access the experimental equipment anytime and anywhere. However, the disadvantages were that a set of experimental equipment can only carry out a class of experiments at the same time, and it cannot support concurrent access of multiple users as long as there were sufficient the resources of the virtual simulation system such as computing, storage and communication bandwidth, etc.

It can be concluded that the construction of advanced mobile communication laboratories is the characteristic of communication specialty in a college. An effective way to improve the efficiency of experiments and the utilization of equipment is online laboratories based on virtual-real combination. It is benefit to strengthen the understanding of theoretical knowledge in the stage of theoretical verification and improve the ability of the experimenter to connect theory with practice. Furthermore, the utilization of experimental equipment will be improved greatly in the stage of engineering practice.

2.2 The Necessity to Constructing Experimental System Based on Virtual-Real Combination

The construction of mobile communication laboratories in university is facing many challenges with the rapid development of mobile communication technology. It is particularly necessary to use virtual simulation technology as a supplement and extension of mobile communication laboratories, which is favored by students for the advantages of flexible experiment time, independent progress, realistic environment, interesting operation, multiple drills and so on by integrating the virtual experiment and online learning. It would be an inevitable trend of college study to construct a mobile communication experimental study environment based on virtual-real combination.

(1) The development and update of mobile communication is being in an accelerated stage at present. The existing experimental equipment are difficult to keep up with the rapid development of mobile communication technology. The technologies involving certain limitations due to the relatively fixed experimental study projects in the existing laboratories and the experimental content that implemented in mobile communication experiment is obviously fail to meet the needs of the society and difficult to keep pace with the times.
(2) It is difficult to build a systematic experimental knowledge system. Due to some instruments and equipment used for mobile communication experiments are expensive, it will load some difficult to systematically construct a real-world experimental environment for mobile communication. Students are difficult to establish a systematic knowledge system of mobile communication because of the systematic deficiency of authentic and exploratory in mobile communication experiment environment.
(3) Those existing experimental environment were difficult to meet the requirements of continuous enrollment expansion. It was difficult for every student to fully carry out experiments for the lack of experimental space, experimental funds and experimental equipment in mobile communication experimental environment (Vogel et al., 2022; Kong et al., 2021). Therefore, to change the existing mobile communication experiment mode is imperative. It can provide a new strain way for mobile communication experiment strategy by building a hybrid experiment mode based on online and offline study combined virtual with real study environment.
(4) The high requirements for practitioners come from mobile communication industry. As the progress of mobile communication technology, the practical ability of students majoring in communication is required to be constantly strengthened in the mobile communication industry. Students are required to not only master the relevant theoretical knowledge of the major, but also pay more attention to practical ability and innovation ability. It will be difficult to adapt to the development needs of the mobile communication industry if a student lacks practical ability and innovation ability.

There are several obvious advantages for online virtual experiment environment compared with the traditional mobile communication box type experimental study environment. The online virtual experiment is not limited by the site, equipment, natural environment and other factors. At the same time, the online virtual experiment is contributed to planning of experiment time flexibly, shared network resources, lifelike environment, interactive operability, interesting operation, independent experiment, repeated drills and so on. Students can arrange experiments according to their own planning and will be attracted by the verisimilitude and immersion of the experimental operations. So, the interest and motivation of the students in experiments are enhanced greatly. The mobile communication experiment mode based on virtual-real combination can not only relieve the pressure of frequent updating of large experimental equipment in colleges or universities, but also help students to understand and master the complete experimental process through intuitive, clear, lifelike and interactive experiments, which would be beneficial to establish a systematic understanding of mobile communication experiments so as to improve students' practical and innovative abilities.

3. EXPERIMENT SYSTEM BASED ON VIRTUAL-REAL COMBINATION

3.1 Planning of Virtual-Real Combination for Mobile Communication Experiment

Mobile communication was an important professional course for students majoring in electronic information. Experimental teaching is a teaching link that undertakes the important task of integrating theory with practice. It is necessary to design a system experiment related to 5G mobile communication system in order to make learners understand the latest trend of communication technology.

In terms of experimental content, in addition to designing some classical systematic experiments, such as analog modulation transmission system and digital modulation transmission system, it is necessary to design a system experiment related to 5G mobile communication system in order to make learners understand the latest trend of communication technology and provide a personalized development platform for those who have spare power (Li et al., 2022; Zhang et al., 2021). As the latest generation of mobile communication system entering the practical stage, 5G mobile communication system has good novelty and systematic, in which each functional module of its physical layer corresponds to the contents of different chapters in the course of communication courses. By introducing the relevant knowledge of 5G physical layer into the teaching of communication principles, the problem of combining mobile communication teaching with engineering application can be solved efficiently.

To achieve a complementary advantage of virtual simulation and online reality technology, the experiments could be designed by combining respective technologies at different experimental levels. Some experiments of theoretical verification and algorithm can implement on virtual platform so as to reduce or even eliminate errors, shorten the time of the hardware experiment, and improve the efficiency of the experimental hardware. For experiments of jointing and debugging of hardware and software, the virtual-real combination technology can be used to enable the students to access the experimental hardware in the laboratory through the network so as to carry out remote online reality experiments. In this way, the experimental effects can be completely consistent with the engineering practice. The limited experimental equipment was used fully through carrying out experiments at different peaks.

The operation of mobile communication network can be simulated through the technologies of digital media based on some technologies including the Internet, virtual reality, cloud computing and big data and information technology. The collaborative mode of combining online virtual experiments and real experiments can be implemented, which reduced the cost and expansion difficulty of the mobile communication experimental system greatly. So, the experimental operation became more convenient and the utilization of experimental equipment were improved to some extent. At the same time, it would contribute to enhance the students' understanding on the theory of mobile communication and the perceptual cognition of mobile communication equipment. In addition, the teaching on mobile communication experiments based on virtual-real combination can also effectively solve the contradiction for capital budget between the limited experimental equipment and the large number of students.

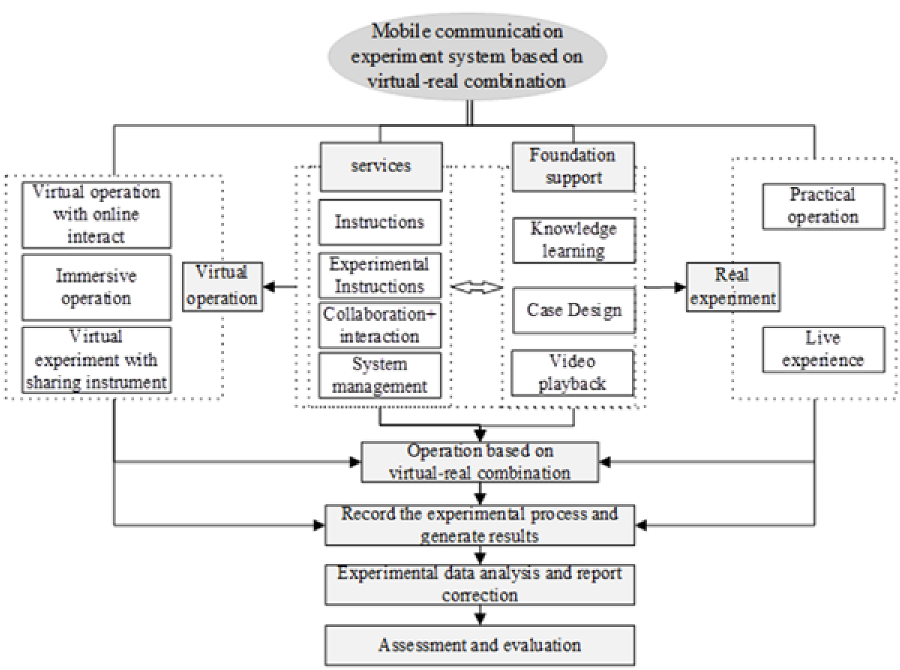
3.2 System Architecture

Guided by technical characteristics, strengthening practice and innovation ability, the experimental system of mobile communication based on the combination of virtual and real is designed as Figure 1.

The mobile communication experimental system based on virtual-real combination was composed of several modules, such as virtual experiment, real experiment, experimental service, basic knowledge support, experimental analysis and experimental evaluation. The experimental service module includes operation instructions, experimental guidance, cooperative operation, interactive communication, and experimental management. The basic knowledge support module includes the cognition of mobile communication theoretical knowledge and practical knowledge system, case design and experimental video playing. Real experiments include actual operation and on-site experience, while virtual experiments include software sharing, instrument sharing and remote-control virtual experiments. Virtual environment was a supplement and extension of real reality. In addition, the process and results of students' experimental operation would be recorded in the server, which can be used for experimental data analysis and experimental evaluation.

The experimental service module provides the experimental operation platform, related management, the operating instructions and guidance for the experimenter. The experimenter can cooperate and interact through the system. Furthermore, the basic experiment module study was also supported for experimenter's study to enhance the understand about relevant basic theories and knowledge points. The video playback could reproduce real-time teaching process of mobile communication experiments for students. It was helpful for students to watch video installation demonstration and configuration of large mobile communication equipment during the deployment of LTE. For instance, students can be familiar with related equipment and the guild of configuration operations involving eNodeB in the installing experiment of TD-LTE by watching video playback which showed overall configuration of communication environment and field environment simulation of the machine room exterior. The overall configuration contained equipment selection, placement, the connection between the signal line and the power line, which ensure that smooth communication with correct equipment and relevant auxiliary material models was placed at the designated locations. After self-online video learning, students can be familiar with the process of experimental operation, which will contribute to understand the corresponding experimental operation and related knowledge more clearly for students.

Figure 1. The design of virtual and real experiments in mobile communication system



It is necessary for the experiments based on virtual-reality combination to get the support of physical equipment in real scene, which can be implemented through setting or modifying the input parameters of the physical experiment equipment to share laboratory resources remotely. According to the demand for teaching reform of mobile communication course, the system architecture of virtual-reality combination experiments for mobile communication was presented as Figure 2.

In the system, the functional units such as virtual experiments servers, virtual reality experimental equipment, and virtual experiment terminal, realistic instruments and software platform for wireless innovation were connected through a network. The main experiments based on virtual-reality combination and the management functions of the entire system could be achieved through deploying virtual experimental modules, experimental resources and experimental management modules on the server. The experiments could be executed on realistic experiment equipment includes a radio platform, online test instruments and online experiment terminals by network.

3.3 Implement Process of Experiments Based on Virtual-Real Combination

The experiments could be implemented in virtual scene, realistic scene or virtual-reality combination scene, which would be selected by experimenters. Before starting the experiment, the experimenter should choose which experimental environment would be used. If he chooses a real experimental environment, he should make an appointment with the experimental administrator. Otherwise, the experimenter needs to determine whether to connect the equipment in the real laboratory during the virtual experiment. If necessary, the experimenter needs to reserve the experimental equipment with the laboratory administrator in advance so as to set up the experimental equipment for connecting with the online environment. If experimenter determines the experiment in the virtual environment, he will select and connect the virtual device. After parameters have been set, the experiment can be carried out directly. The experimental flow for experimenters was described as Figure 3.

(1) Virtual scene. It was not necessary to use laboratory hardware equipment in virtual scene. Experimenter can start the experiment at any time after selecting the experiment model of virtual scene. The

Figure 2. The system architecture of virtual-reality combination experiments

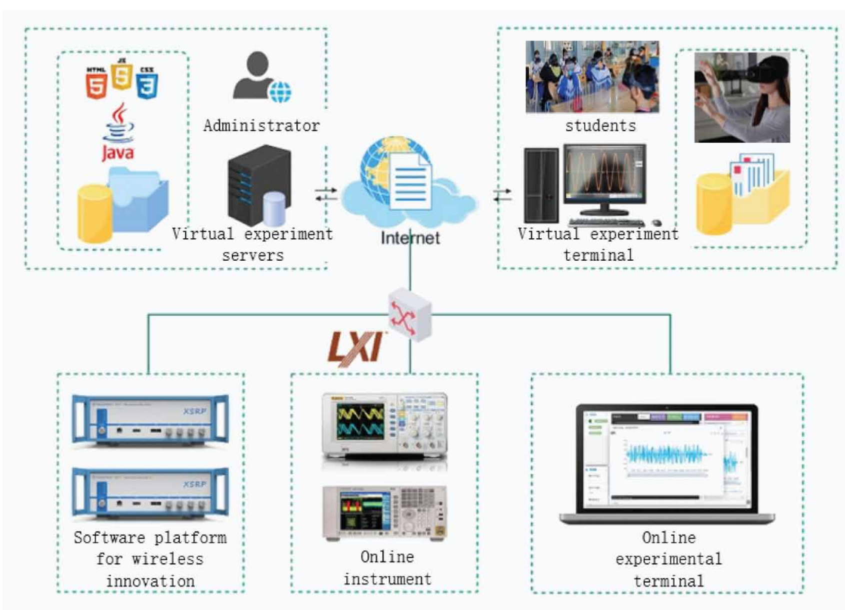
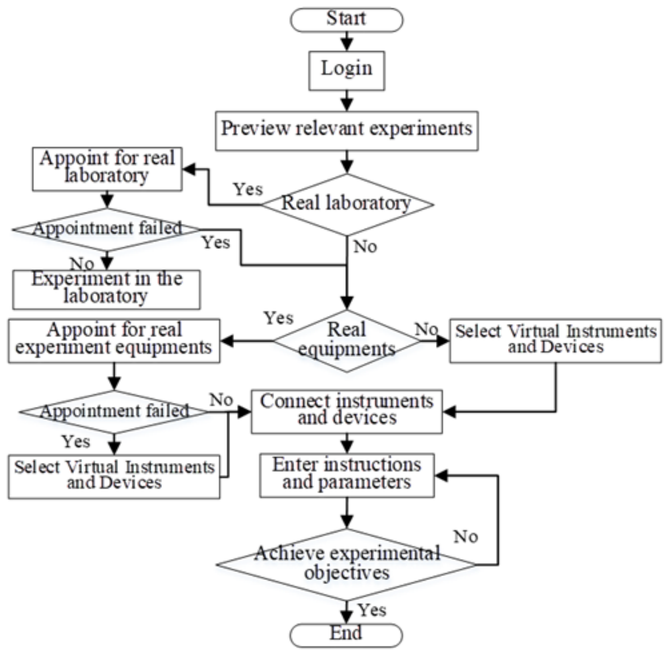


Figure 3. The experimental flow for experimenters



relevant requests from the experimenter on the experiment terminal or virtual equipment were sent to the virtual server through the network. The server invokes the experimental calculation software module through a pre deployed service. After processing, the experimental output results would be returned to the experiment terminal or virtual equipment, by which the rendered picture or data of the experimental results would feed experimenter. The experimental interface could be obtained in experiment terminal or virtual equipment by accessing the virtual server, then the experimenter set the corresponding parameters of the virtual device, and the graphical display of the experimental results, data, etc., would be displayed on the experiment terminal or virtual equipment.

(2) Realistic scene. The experimenter can conduct experiments on real experimental equipment in physical laboratory as long as conditions permit.

(3) Virtual-real combination scene. The physical experiment equipment in laboratory used by experimenter with virtual-real combination needs to make an appointment in advance. Furthermore, the experiments can be carried out through remote access to the experimental system within the reserved time period. During the experiment with virtual-real combination, the equipment service of virtual experiment was deployed in the physical equipment in laboratory, in which a virtual experiment corresponds to a set of physical experiment equipment. The input data and parameters operated in virtual simulation server was transmitted to physical equipment in real environment by the precession of online experiment terminal service to keep synchronization between virtual terminals and physical terminal. Then the experiment task was processed in physical equipment in real laboratory and the experimental results will be returned to the operational terminal by the way of images, tables, data or video captured from physical instruments.

3.4 Three-Dimensional Virtual Design of Mobile Communication Experiment

The communication mathematical model and the entity model in the mobile communication experiment are integrated to build a coordinated system through appropriate technical strategies. In the three-dimensional virtual design of mobile communication experiment, the overall pictures of virtual experiment scenes and virtual instrument objects were selected as the background of the experiment generally and those dynamically operation objects were embedded in their corresponding positions (Y. Zhou, et al. 2018). Based on dynamic refresh in the virtual dynamic model and responses to real-time events, a complete virtual experimental model could be constructed. In addition, the network technology and digital media were integrated into virtual environment.

Guided by the base station installation of TD-LTE, a design course of three-dimensional virtual experiment project can be created on the ground of the selection of training experiment content, designing of experiment script, making model and animation and experiment development and implementation used by the tools of 3D Max and Unity 3D (Quiroga et al. 2019). In the virtual experimental environment, students can allocate the IP for each virtual components, config business to install the base station equipment and connect these virtual components with cables following the standardized operation process. The design and operation process of the virtual experiment for TD-LTE base station installation was provided as Figure 4.

The experiment of the connection between equipment and signal line is an important learning content in the design and operation of the virtual experiment for TD-LTE base station installation, in which main parts of the experiments included equipment selection, equipment connection, connection line selection, etc. The experiment process mainly includes the installation of BBU cabinet, PTN cabinet and ODF rack. Three devices RRU selected and installed on the top of tower. Then the connection between BBU and RRU can be operated. At last, the switching between devices was carried out according to the equipment instruction diagram. Through virtual connection operation, the BBU and RRU were connected with LC-LC optical. The interface of the connection operation between BBU and RRU in virtual experiment was shown in Figure 5.

The connection operation between RRU and antenna in the virtual experiment of TD-LTE base station installation was shown in Figure 6. In the experiment, the main operations were to connect RRU1, ANT1 and ANT4 of the antenna, RRU2, ANT2 and ANT5 of the antenna, RRU3 and ANT3 and ANT6 of the antenna.

The following operations was to connect BBU and GPS, BBU and PTN, PTP and ODF. The lines of GPS feeder were selected to connect the BBU and GPS between the port IN and device GPS. Then select some pairs of LC-LC optical fiber cables to connect the BBU and PTN, PTN and ODF. In this way, the installation of TD-LTE base station equipment and the design of signal line connection in the virtual experimental environment are basically completed.

3.5 Construction of Resources

The current on-site experimental study of mobile communication discipline is difficult to meet the ability needs of modern communication industry although the real experiment forms the perceptual knowledge and real experience for students. The shortcomings of the real experiment can be made up by the experiment based on virtual-real combination. It will enhance the perceptual knowledge of the

Figure 4. The flow of design and operation on virtual experiment

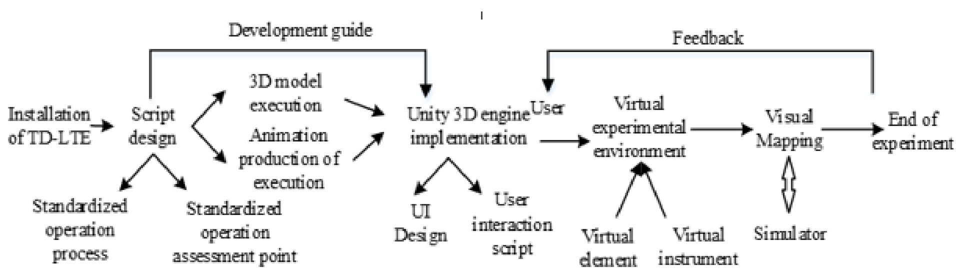


Figure 5. Connection operation between BBU and RRU in virtual experiment

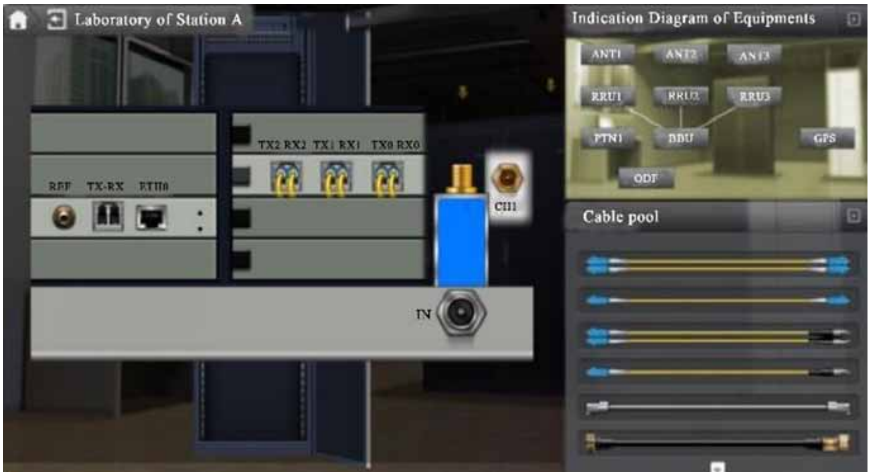


Figure 6. Connection operation between RRU and antenna in virtual experiment

experimenter, stimulate the learning interest of the experimenter, improve the exploration ability of the experimenter, and strengthen the practical ability of the experimenter. The mobile communication virtual experiment provides supplement and extension for the real laboratory. Therefore, the experimental system needs to build corresponding experimental resources to support and improve the combination of virtual and real experiment, including virtual experiments, experimental services, supporting knowledge, experimental analysis and experimental evaluation.

1) Supporting knowledge.

To master the theory and relevant knowledge of mobile communication, some supporting knowledge is required, which focuses on the cognition, case design and experimental video playing of mobile communication theoretical knowledge and practical knowledge. For students, it will beneficial to get familiar with the corresponding experimental contents independently after learning theoretical knowledge by learning those professional basic courses, professional core courses, experimental training courses of professional comprehensive, and arranging theoretical and experimental courses, which will lay a foundation for students to further master the application and practical operations of mobile communication experiment. Students can plan their own learning according to individual's need through watching the video to learn the auxiliary study material of mobile communication experiment course integrated the theory teaching and experiment teaching of mobile communication course. There will lay the foundation for students to master the basic content of knowledge and experiment operations professionally through the learning of knowledge support module of the mobile communication experiment teaching based on virtual-real combination.

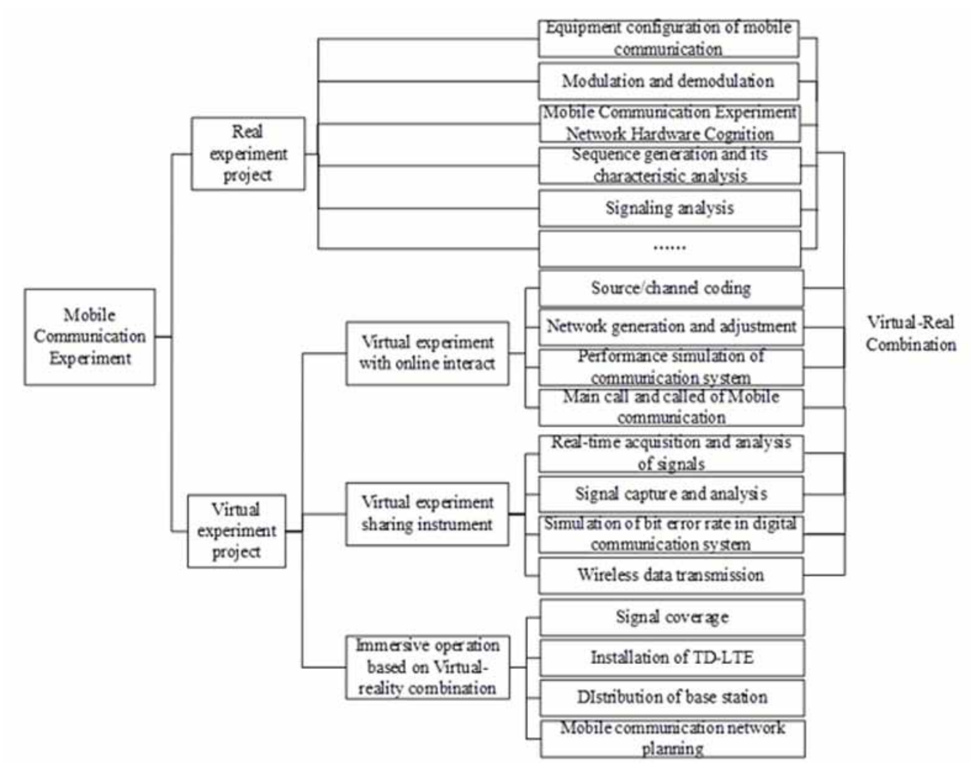
2) Experimental services.

To prepare for correct and effective experimental operation, it is necessary to provide some relative experimental operation instructions including experimental purpose, experimental content, experimental assessment requirements, collaboration and interaction, experimental management, etc.

3) The construction of experimental content combining virtual and real.

Virtual-real combination experiment laboratory will be a supplement and extension of the real laboratory in mobile communication experiment system, which provides several experiment modes as shown in Figure 7 for students to learn the course about mobile communication.

Figure 7. Framework combined with virtual and real experiments of the mobile communication



There are four components in the framework combined with virtual and real experiments of the mobile communication which contained real experimental environment, interactive virtual online experiment, immersive virtual reality experiment, and instrument sharing in network virtual experiment. (a) Interactive virtual online experiment. By establishing various virtual experiments models to simulate the real scene of mobile communication, in which the experimenter can perform detailed operations with conduct interface interaction and get the experimental results by presenting the three-dimensional interfaces one by one. (b) Immersive virtual reality experiment. The high-definition virtual experimental equipment of mobile communication was adopted based on graphics equipment, graphics generation algorithm, human-computer interaction technology, etc. (c) Instrument sharing in network virtual experiment. In the course of mobile communication experiment, the corresponding experimental parameters and the operation instructions can be transmitted to the corresponding actual instrument through the data line by operating the virtual instrument control panel. Then the given task of experiment will be completed on the real experimental instrument and the experimental results will be fed back to the online operator through the virtual instrument and the system

4) Collection and evaluation of experimental data.

The mobile communication experiment system can record the relevant data in the process of the experimenter's operation in real time, mainly including the learning progress, learning times, cumulative learning duration, various parameters set in the operation, the completeness of experiment, the precision of experiment results, and the comprehensive evaluation score. The corresponding experiment report can be generated automatically with the data recording and statistic the course of the experiment after each experiment, which mainly includes the experiment name, operation time, experimental devices, experimental methods, experimental procedures, experimental results and analysis.

3.6 Assessment and Evaluation for Study

The virtual-reality combination experimental system of mobile communication effectively overcomes the deficiencies of real experiment and virtual experiment in case of separation. The virtual experiment is the supplement and extension of the real laboratory while the real laboratory provides a kind of physical experience and perception for experimenters. The practical ability and skills of students can be improved by operating and practicing in highly realistic virtual environment. The learning effect of experiments based on virtual-reality combination can be evaluated objectively and efficiently by integrating behavior record, experiment operation and experiment results oral defense.

(1) Behavior evaluation of the experimental process. The whole process of online and offline experiments can be evaluated relying on the whole process of students' operation behaviors automatically recorded during experiment.
(2) Evaluation of experimental operation. The acceptance of each experimental task is carried out according to the evaluation content involving the experimental operation scheme, division of labor and node progress, and.
(3) Evaluation of experimental results. The evaluation for practice results can be achieved objectively and truly by comparing between the students' operation and the standard operation with matching algorithm executed on experiments result and records timely in the practice process. The evaluation includes the operation and implementation results of experiment.
(4) Curriculum assessment. Students' comprehensive practical ability can be assessed through oral defense and demonstration of experimental projects.

4. EFFECT EVALUATION FOR EXPERIMENTAL SYSTEM

In this section, a real-world testing of mobile communication has been conducted by the members of our research class. The students were selected as test objects who were major in electronic information engineering school of information science and engineering of Jiaxing University in past three years. The experimental teaching based on virtual-real combination were evaluated according to students' curriculum achievements, students' professional abilities and teaching feedback.

4.1 Analysis of Curriculum Achievements

In order to analyze the teaching effect of the mobile communication experimental system based on virtual-real combination, the analysis of curriculum Achievements was indispensable. "Mobile communication" was selected as the evaluation curriculum and the duration of the experiment was one semester. The examination objects were students in 2020 grade who were studying in their junior year. They have studied professional basic courses and have a certain professional foundation. The students were divided into a regular class and an experimental class with 33 and 28 students respectively. The theoretical knowledge of curriculum all were taught by the same teacher while the experiments of the curriculum were carried out based on traditional experimental model for regular class and the virtual-real combination experimental model for experimental class. Experiments conducted in groups of 2-3 students. The theoretical and experimental teaching were carried out twice a week respectively for all students. A test as pre-test was conducted at the beginning of the semester and a test as post-test was conducted at the end of the semester for all students. The course of "Communication Principles" that students have learned in the previous semester was as pre-test subject and the course of "Mobile communication" that students were learning was as post-test subject.

Whether students have completed the expected learning tasks was as the main assessment standard which focused on assessing students' understanding of knowledge and their ability to apply knowledge. The composition of the final score were as Table 1.

(1) Comparative analysis of students' score

To explore whether there were differences in curriculum scores of the experimental class before and after the semester, the statistics at the two levels of descriptive and inferential were calculated. The t-tests were analyzed on the score of pre-test and post-test to verify whether there were some significant differences in the average scores between the experimental class and the regular class. The comparative analysis of achievements was shown in Table 2.

As shown in the Table 2, there was no significant difference ($p=0.546>0.05$) in curriculum scores of pretests between the experimental class and the regular class. It was clear that the pre-test scores of curriculum scores in the experimental class and the regular class were homogeneous and students' initial curriculum knowledge level were relatively consistent. So, it is feasible to analysis significant differences of curriculum achievements based on experiment class and regular class. There was a significant difference ($p=0.042<0.05$) in curriculum scores of posttest between the experimental class and the regular class. It could be concluded that the curriculum achievements were significantly improved for those students in experiment class who had learnt through practice of experimental teaching based on virtual real combination for a semester. Due to the increasingly difficult understanding of mobile communication knowledge, the overall difficulty of students' knowledge has increased, and students' mastery of knowledge may not be sufficient, resulting in a slight decrease in the average score of the Regular Class. The immersive experimental experience anytime and anywhere not only strengthened students' hands-on ability, but also enhanced students' understanding of theoretical knowledge.

Furthermore, the final curriculum scores of Mobile Communication were counted for students coming from a regular class and an experimental class in grade 2020 who major in electronic

Table 1. Curriculum evaluation system

Item				Total score	Ratio
Theory	Knowledge cognition	Concepts and principles		100	10%
		Cognition			9%
		Method understanding			9%
		Comprehensive understanding			9%
	Analysis & application	Design		100	8%
		Analysis			5%
		Application			5%
Practice	Design & maintenance	Feasibility		100	4%
		Correctness maintenance			3% 3%
	Optimize & innovation	Efficiency		100	4%
		Accuracy			3%
		Innovation			4%
	Engineering literacy	Basic quality	Cooperation & coordination	100	2%
			Strain capacity		2%
			Observation & maintenance		2%
		Operational process	Clear steps Accurate operation		4% 5%
		Results	Completeness		3%
			Accuracy		3%
			Answer questions		3%

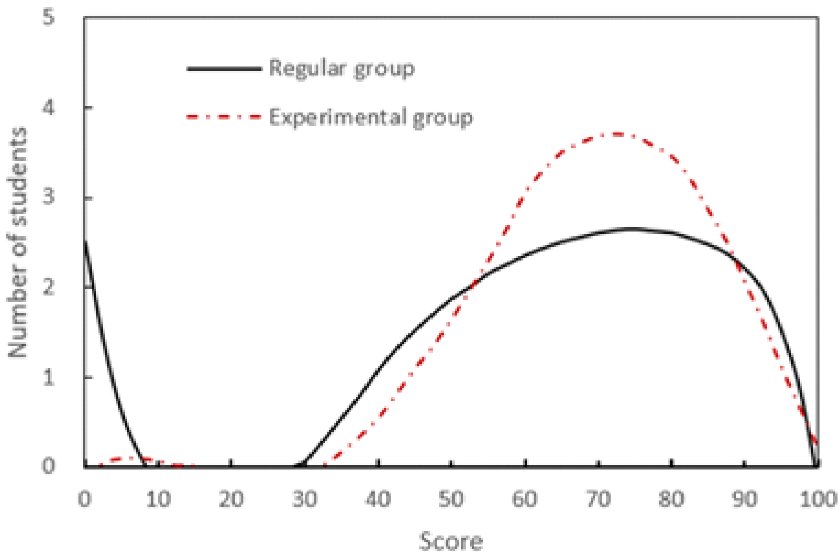
Table 2. t-test on independent scores

Score	Pre-post test	Class	Number	Mean	Levene's Test		*t*-Test		
					F	Sig.	t	df	Sig. (DT)
Score of course	Pretest	Experiment	28	69.264	0.105	0.748	2.182	60	0.546
		Regular	33	68.837					
	Posttest	Experiment	28	74.981	0.005	0.9523	1.496	60	0.042
		Regular	33	66.778					

information engineering and the comparative analysis of achievements between regular class and an experimental class was shown in figure 8.

It can be seen from figure 8 that the theoretical and experimental scores of students in experimental class with experiments teaching of virtual-real combination were higher than those of the students in the regular class. As far as the score distribution were concerned, the score distribution of the students in the experimental class is closer to the normal distribution than regular class and the average score of experiment class was 74.283 which was higher than regular class. It was obvious the teaching of mobile communication experiment teaching based on virtual-real combination was superior.

Figure 8. Score comparison between different classes



(1) Comparative analysis of students' abilities

In order to explore whether there are differences in knowledge cognition, design and maintenance, analysis and application, optimization and innovation, and engineering literacy training for regular class and experimental class respectively. The t-tests on independent capability samples of the horizontal pretest and posttest in experimental class and regular class and the results were shown in Table 3.

Table 3 shows that before the experiment, there was no significant difference in ability of knowledge cognition ($p=0.165>0.05$), design & maintenance ($p=0.411>0.05$), analysis & application ($p=0.937>0.05$), optimize & innovation ($p=0.517>0.05$) and engineering literacy ($p=0.776>0.05$) between the experimental class and the regular class. It was clear that the experimental class and the regular class were homogeneous and students' initial capability level were relatively consistent. So, it is feasible to analysis significant differences of capability evaluation based on experiment class and regular class. After a semester of experimental teaching based on virtual-real combination, there were significant differences in ability of design & maintenance ($p=0.013<0.05$), analysis & application ($p=0.033<0.05$), optimize & innovation ($p=0.038<0.05$) and engineering literacy ($p=0.023<0.05$) between the experimental class and the regular class except in ability of knowledge cognition ($p=0.805>0.05$).

In order to further analyze the differences in students' abilities before and after the experiment, it is necessary to conduct a longitudinal comparative analysis of the ability of knowledge alignment, design & maintenance, analysis & application, optimization & innovation, and engineering quality between the experimental class and the regular class. The results of t-test on abilities paired samples for pretest and posttest in experimental and regular classes were shown in Table 4.

Table 4 show that there was no significant difference in the ability of knowledge cognition in experimental class ($p=0.550>0.05$) before and after the experiment as well as regular class ($p=0.435>0.05$). There were significant differences in the ability of design & maintenance ($p=0.028<0.05$), analysis & application ($p=0.031<0.05$), optimize & innovation ($p=0.024<0.05$) and engineering literacy ($p=0.036<0.05$) in experimental class before and after the experiment. It showed that the ability of knowledge cognition did not significantly improve, but the cooperative communication ability of design

Table 3. t-tests on independent capability samples in experimental class and regular class

capability	Pre-post test	Class	Number	Mean	Levene's Test		*t*-Test		
					F	Sig.	*t*	df	Sig. (DT)
Knowledge cognition	Pretest	Experiment	28	73.362	5.016	0.032	1.380	60	0.165
		Regular	33	74.334					
	Posttest	Experiment	28	74.963	0.557	0.454	-0.152	60	0.805
		Regular	33	68.317					
Design & maintenance	Pretest	Experiment	28	65.375	5.973	0.016	0.864	60	0.411
		Regular	33	67.187					
	Posttest	Experiment	28	71.751	0.025	0.853	2.115	60	0.013
		Regular	33	63.632					
Analysis & application	Pretest	Experiment	28	62.361	6.045	0.015	0.836	60	0.937
		Regular	33	64.187					
	Posttest	Experiment	28	65.544	0.026	0.871	2.228	60	0.033
		Regular	33	61.238					
Optimize & innovation	Pretest	Experiment	28	65.361	5.327	0.015	0.836	60	0.517
		Regular	33	61.187					
	Posttest	Experiment	28	69.544	0.026	0.871	1.048	60	0.038
		Regular	33	60.173					
Engineering literacy	Pretest	Experiment	28	71.708	0.691	0.421	-0.312	60	0.776
		Regular	33	72.102					
	Posttest	Experiment	28	83.857	0.086	0.944	2.098	60	0.023
		Regular	33	72.852					

Table 4. t-test on abilities paired samples for pretest and posttest in experimental and regular classes

capability	Class	Number	Mean		*t*-Test			
			Pretest	Posttest	C. C.	*t*	df	Sig. (DT)
Knowledge cognition	Experiment	28	73.362	74.963	0.404	-0.673	30	0.550
	Regular	33	74.334	68.317	0.215	-0.728	30	0.435
Design & maintenance	Experiment	28	65.375	71.751	0.537	-2.409	30	0.028
	Regular	33	67.187	63.632	0.581	-1.287	30	0.236
Analysis & application	Experiment	28	62.361	65.544	0.540	-2.535	30	0.031
	Regular	33	64.187	61.238	0.372	-1.298	30	0.185
Optimize & innovation	Experiment	28	65.361	69.544	0.546	-2.672	30	0.024
	Regular	33	61.187	60.173	0.457	-1.405	30	0.207
Engineering literacy	Experiment	28	71.708	83.857	0.472	-2.238	30	0.036
	Regular	33	72.102	72.852	0.321	0.528	30	0.615

& maintenance, analysis & application, optimize & innovation and engineering literacy were significantly improved. The reason why there was no significant difference in the ability of knowledge cognition for experimental class before and after the experiment might be that the theoretical basis was particularly important with learning deeply in theoretical knowledge. The reasons for the significant improvement in the ability of design & maintenance, analysis & application optimize & innovation and engineering literacy might be as follows. Firstly, students could verify their knowledge and assumptions anytime and anywhere, which enhances their enthusiasm for learning. Secondly, with the influence of continuous practice, an experiential teaching environment was created based on virtual-real combination and thereby students were obtaining more opportunities to apply technology of virtual-real combination environment to improve their information nutrition, innovation ability, and hands-on ability.

It was clear that students' ability of design & maintenance, analysis & application optimize & innovation and engineering literacy could be improved significantly through experiential teaching based on virtual-real combination. The ability to practice and the enthusiasm to participate of students in experimental class have significantly improved. At the same time, the concepts and knowledge in mobile communication course could be understood more clearly through experimental teaching of virtual-reality combination. The curriculum objective achievements of the students in the experimental class acquired obvious advantages over the students in the regular class because of the guaranteed practical experimental environment. The achievement evaluation value of knowledge cognition, design and maintenance, analysis and application, optimization and innovation, and engineering literacy training were all far higher than that of the students in regular class. Through the analysis of the behavior evaluation of the experimental process, the evaluation of the experimental operation, the evaluation of the experimental results, and the examination of the oral defense at the end of the class, the classroom atmosphere using the experimental system of virtual-real combination was obviously better than the regular class.

4.2 Investigation Analysis

In order to understand the cognition and attitude of students to the experiment based on virtual-real combination, three types of students including production training, curriculum design and experiments were selected as respondents who all came from electronic information engineering school of information science and engineering. The anonymous investigations were carried out through questionnaire which contained following seven items.

(1) Are you interested in experiment based on virtual-real combination?
(2) Is it helpful to understand the abstract concepts in mobile communication?
(3) Is it helpful to master the working principle of wireless signal transmission?
(4) Is it helpful to be familiar with implementation of mobile communication engineering?
(5) Do you often cooperate and communicate with classmates in the experiment?
(6) Whether the efficiency of experiment based on virtual-real combination is high compared with real experiment?
(7) Are you more willing to choose experiments based on virtual-real combination comparing to real experiments?

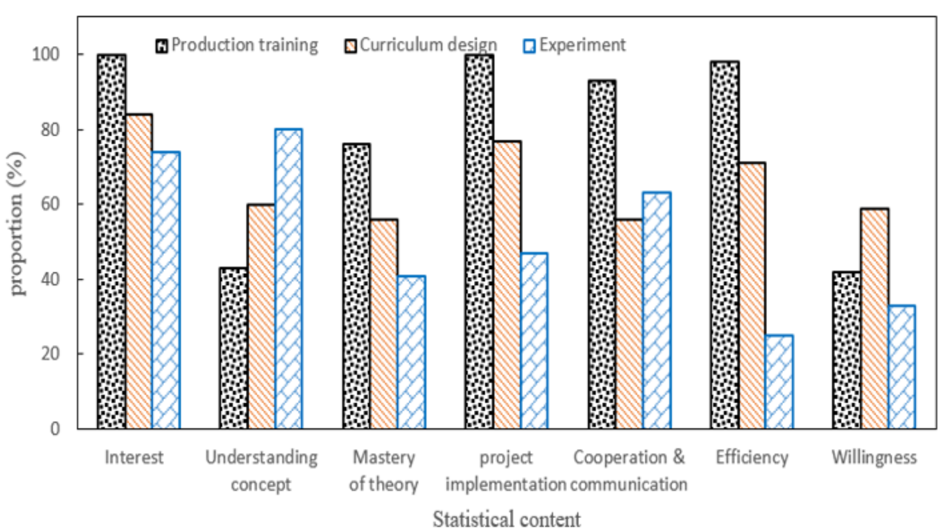
The direct purpose of experimental teaching was to enable students to quickly and better adapt to their job. To guarantee the comprehensive and reasonable feedback to the experimental teaching based on virtual-real combination as much as possible, the investigations were carried out among the students in primary grade, higher grade and graduate grade. Considering the content that interviewees were currently learning, the experiments of students in primary grade, curriculum design of students in higher grade, and production training of students in graduate grade were chose as the survey subjects. The number distribution of interviewees was shown in the figure 9. There were 26, 29 and 26 interviewees coming from grade 2019, 2020 and 2021 respectively.

Figure 9. Distribution of the number of interviewees in different grades

According to counting, there were 81 interviewees distributed in the investigation and 79 questionnaires were finally recovered contained 25 for production training, 28 for curriculum design and 26 for experiments. The recovery rate was 97.53% and the results of investigations were shown as figure 10.

Viewing from figure 10, the students of production training were very interested in the experiments based on virtual-real combination. They believed it was beneficial to mastering the working principle of wireless signal transmission and was familiar with implementation technology of mobile communication engineering. There were a lot of cooperation and communication during their experiment. The efficiency of experiment was very high. Some interviewees thought that the experiments based on virtual-real combination was not very helpful to understand the abstract concepts in the theoretical study comparing to real experiments. However, the students of curriculum design had a balanced evaluation in all aspects. Most of them were very interested in the experiments based on virtual-real combination, and half of them thought it was very helpful to understand the abstract

Figure 10. Investigation analysis of three types of students in seven aspects



concepts in the theoretical study and to master the working principle of wireless signal transmission. There was more communication between students. The efficiency of the experiment was also relatively high. So, the experiments based on virtual-real combination and real experiments in laboratory were acceptable for them. For the students of course experience, more than 75% of students were very interested in the experiments based on virtual-real combination. They think that the experiment was helpful to understand the abstract concepts that appeared in the theoretical study. However, most of them thought it was not very helpful for them to grasp the working principle of wireless signal transmission and the project implementation of mobile communication engineering. Therefore, the efficiency of experiments is not very high which loaded low willingness to complete the experiment under the environment of virtual-real combination.

It was clear that different students have different harvest. On the whole, the effect of the experiments based on virtual-real combination was better than experiment in real library. The effect of experiments based on virtual-real combination was relatively superior comparing to real laboratory and online environment. Students could arrange the experiments according to their own actual situation, which made the experiment time abundant. At the same time, students could also partially operate real instruments and equipment online, which not only help students to experience a convenient and immersive environment, but also the experimental efficiency could improve fully.

Therefore, it was necessary to construct an experimental system of mobile communication as much as possible according to a principle of physical laboratory prior and virtual-real combination, which will be helpful to achieve the goal of experimental study. However, the physical devices in laboratory provided to operate in virtual environment were not sufficient. It is difficult to realize the fully virtual-real combination to operate physical devices by sending instructions in virtual environment.

5. CONCLUSION

As a supplement and extension of real experimental system in space and time, the resources sharing, expand and flexibly personalized experiments can be realized through experimental system based on virtual-reality combination for mobile communication teaching so as to alleviate the problems such as rapid iteration of mobile communication technology, high cost of experimental equipment, easy damage, and lack of flexibility and personalization in experiments. Students can experience the actual layout and control of mobile communication being analogue to enterprises by virtual experimental environment, which can deep students' understanding in order to improve the ability of construction of mobile communication network architecture, data configuration, and installation and adjustment for relating instruments, equipment and auxiliary materials. The experimental system based on virtual-reality combination have created the physical situation in virtual platform for students, which has the authenticity of the process situation. It will be benefit to enhance the experimenter's independent learning motivation, expand innovation ability, and improve the quality of mobile communication experimental study greatly. The system provided measurements for evaluating effect of learning objectively through tracking assessment of whole operation process. The constructed experiment system based on virtual-reality combination extends practical teaching and learning, which provides an efficient pathway to improve the teaching and learning quality for students majoring in mobile communication.

6. LIMITATIONS AND FUTURE WORK

It was difficult to realize fully immersive virtual reality in a very short time and the number of physical devices that can be controlled remotely in the laboratory were still limited. In addition, the mobile communication experiment based on virtual-real combination cannot fully simulate the physical world due to the limitation of computing power and software and the experimental equipment in laboratory linked to students by network was preset in advance which loaded that students must appoint with administrator to preset the experimental equipment in each experiment. The future works were to remotely control more physical devices in the laboratory so as to enhance the realism of remote experiments and provide more opportunities for experimenters to operate devices.

ACKNOWLEDGMENT

This research was supported by Higher education collaborative education Foundation of the Education Ministry under Grander No. 202101347006 and 202101355031, the School Scientific Foundation under Grander No. SKQD2021B-035, Innovative industrial design and Research Institute Project under Grander No. cxgy21-004, Guangdong Province Higher Vocational Education Teaching Reform Research and Practice Project under Grant No. GDJG2021385, Guangdong University Innovation Team Project under Grant No. 2020KCXTD045, Guangdong Education Science Planning Project under Grant No. 2021GXJK515.

REFERENCES

Bayram, S. B., & Caliskan, N. (2019). Effect of a game-based virtual reality phone application on tracheostomy care education for nursing students: A randomized controlled trial. *Nurse Education Today*, *7*(9), 25–37. doi:10.1016/j.nedt.2019.05.010 PMID:31102793

Cavanaugh, G., Condry, H. M., Afable, C. F., Morris, M., De, S., Madison, H. E., Marshall, J., Victor, C. P., & Weiner, M. (2023). Immersive Learning and Participatory Engagement: Connecting in the Online Classroom Through Virtual Reality. [IJDET]. *International Journal of Distance Education Technologies*, *21*(1), 1–19. doi:10.4018/IJDET.317364

Chavez, B., & Bayona, S. (2018). Virtual reality in the learning process. In Trends and Advances in Information Systems and Technologies, 26 (6), 1345-1356. doi:10.1007/978-3-319-77712-2_129

Chen, X., Chen, H., Guo, S., Li, J., Zhang, J., & Li, Z. (2021). A virtual reality experiment system for an introductory computer hardware course. *Computer Applications in Engineering Education*, *29*(6), 1702–1717. doi:10.1002/cae.22418

Cheon, J., Lee, S., Crooks, S. M., & Song, J. (2021). An investigation of mobile learning readiness in higher education based on the theory of planned behavior. *Computers & Education*, *59*(3), 1054–1064. doi:10.1016/j.compedu.2012.04.015

Degli Innocenti, E., Geronazzo, M., Vescovi, D., Nordahl, R., Serafin, S., Ludovico, L. A., & Avanzini, F. (2019). Mobile virtual reality for musical genre learning in primary education. *Computers & Education*, *139*, 102–117. doi:10.1016/j.compedu.2019.04.010

Ding, Y., Li, Y., & Cheng, L. (2020). Application of Internet of Things and virtual reality technology in college physical education. *IEEE Access : Practical Innovations, Open Solutions*, *8*(2), 96065–96074. doi:10.1109/ACCESS.2020.2992283

Ferri, F., Grifoni, P., & Guzzo, T. (2020). Online learning and emergency remote teaching: Opportunities and challenges in emergency situations. *Societies (Basel, Switzerland)*, *10*(4), 186–198. doi:10.3390/soc10040086

Gao, Y., & He, Y. (2021). Establishment and practice of computer virtual simulation experiment teaching platform. *Software Guide*, *9*(3), 267–268. doi:10.11907/rjdk.221542

Gatica-Rojas, V., & Méndez-Rebolledo, G. (2017). Virtual reality interface devices in the reorganization of neural networks in the brain of patients with neurological diseases. *Neural Regeneration Research*, *9*(8), 888–896. doi:10.4103/1673-5374.131612 PMID:25206907

Guan, S., Hu, W., Zhou, H., Lei, Z., Feng, X., & Liu, G. P. (2021). Design and implementation of virtual experiment for complex control system: A case study of thermal control process. *IET Generation, Transmission & Distribution*, *15*(23), 3270–3283. doi:10.1049/gtd2.12259

Jayanthi, K., Srivatsa, S., & Ramesh, T. (2018). Performance evaluation of reusable learning objects in e-learning system-A blended approach to make-learning to work. *Information Technology Journal*, *7*(4), 667–672. doi:10.3923/itj.2008.667.672

Kong, W., Ni, X., & Qu, F. (2021). Research and Practice on Teaching Reform of Optical Communication Based on Virtual Simulation. *Education Teaching Forum*, (36), 119-120. doi: doi:10.16742/j.cnki.sjg.2021.36.0119

Li, Q., Nie, W. Z., Fang, C. H., & Yuan, B. (2022). Exploration on online project teaching based on virtual simulation technology. *Shiyan Jishu Yu Guanli*, *39*(1), 199–203. doi:10.16791/j.cnki.sjg.2022.01.040

Li, T., Zhang, J., & Lin, W. (2021). Design and management of LTE wireless side virtual simulation experiment project. *Laboratory Science*, *24*(2), 70–74. 10z.3969/j.issn.2021.02.017

Li, X., Ye, Z., & Liu, G. (2022). Design of virtual laboratory simulation platform for communication principle. *Shiyan Jishu Yu Guanli*, *38*(10), 261–269. doi: doi:10.16791/j.cnki.sjg.2022.10.048

Luse, A., Brown, A., & Rursch, J. (2021). Instruction in 802.11 Technology in Online Virtual Labs. *IEEE Transactions on Education*, *64*(1), 12–27. doi:10.1109/TE.2020.2998701

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in k-12 and higher education: A meta-analysis. *Computers & Education*, *7*(11), 29–40. doi:10.1016/j.compedu.2013.07.033

Neustock, L. T., Herring, G. K., & Hesselink, L. (2018). *Remote experimentation with massively scalable online laboratories.* In Online Engineering & Internet of Things: Proceedings of the 14th International Conference on Remote Engineering and Virtual Instrumentation REV 2017, Columbia University, New York, USA. doi:10.1007/978-3-319-64352-6_24

Nie, X., Wang, F., & Huang G. (2021). Research on application in information & communications experimental teaching system of virtual simulation. *Laboratory Science*, (5), 424-433. doi:. issn.1672-4305.2021.05.044.10.3969 /j

Quiroga, M. D. M., & Choate, J. K. (2019). A virtual experiment improved students' understanding of physiological experimental processes ahead of a live inquiry-based practical class. *Advances in Physiology Education*, *43*(4), 495–503. doi:10.1152/advan.00050.2019 PMID:31553643

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *14*(7), 103–117. doi:10.1016/j.compedu.2019.103778

Tsai, H. H., Ho, X. Y., Chang, C. T., Tsai, C. Y., Yu, P. T., & Chiou, K. C. (2019). An interactive virtual reality application in education for soil and water conservation. In *2019 International Symposium on Educational Technology (ISET)*, (pp. 60-64). IEEE. doi:10.1109/ISET.2019.00022

Vogel, F., Vahle, N. M., Gertheiss, J., & Tomasik, M. J. (2022). Supervised learning for analysing movement patterns in a virtual reality experiment. *Royal Society Open Science*, *9*(4), 211594. doi:10.1098/rsos.211594 PMID:35601447

Wu, W., & Han, X. (2022). Improvement and perfection of online virtual network laboratory. *Research and Exploration in Laboratory*, *33*(1), 13–27. doi:10.16791/j.cnki.sjg.2022.08.013

Wu, Y., Zhou, Y., & Zhang, W. (2022). Construction and Management of Virtual Simulation Experimental Teaching Center in Communication Engineering. *Shiyan Jishu Yu Guanli*, *34*(5), 218–232. doi:10.16791/j.cnki.sjg.2022.05.055

Xu, C., Xu, M., & Hong, T. (2018). Design of mobile communication experimental system based on virtual reality. *Shiyan Jishu Yu Guanli*, *29*(3), 94–99. doi:10.16791/j.cnki.sjg.2018.03.030

Yang, K. (2019). Exploration on Experimental Teaching System with Hierarchical Communication Principle of Virtual-Real Combination. *Shiyan Jishu Yu Guanli*, *34*(7), 162–165. doi:10.16791/j.cnki.sjg.2017.07.042

Yıldırım, B., Sahin Topalcengiz, E., Arıkan, G., & Timur, S. (2020). Using Virtual Reality in the Classroom: Reflections of STEM Teachers on the Use of Teaching and Learning Tools. *Journal of Education in Science, Environment and Health*, *6*(3), 231–245. doi:10.21891/jeseh.711779

Zhang, M., Ke, J., Tong, L., & Luo, X. (2021). Investigating the influence of route turning angle on compliance behaviors and evacuation performance in a virtual-reality-based experiment. *Advanced Engineering Informatics*, *48*(7), 1012–1025. doi:10.1016/j.aei.2021.101259

Zhao, T., & Shen, Z. (2021). Exploration on the construction of electronic information virtual remote laboratory. *China Distance Education*, *21*(11), 51–58. doi: doi:10.13541/j.cnki.chinade.2021.11.010

Zheng, Y., & Wu, Y. (2020). Design and management of virtual simulation experiment for TD-LTE base station installation. *Shiyan Jishu Yu Guanli*, *35*(10), 125–128. doi:10.16791/j.cnki.sjg.2020.10.031

Zheng, Y., & Wu, Y. (2021). Construction and Management of Virtual Simulation Experiment Teaching Center of Mobile Communication. *Research and Exploration in Laboratory*, *38*(3). doi: doi:10.12713/j.cnki.sjg.2021.03.071

Zhou, E., & Wu, H. (2018). Exploration on the construction of electronic innovation laboratory in higher vocational college. *Journal of Suzhou Vocational University*, *13*(7), 174–183. doi: doi:10.13741/j.cnki.chinade.2018.10.021

Zhou, Y., Wu, Y., & Chang, H. (2022). Construction of Experiment System for Electronic Information Engineering based on Virtual-Real Combination and Graduated Progress. *Research and Exploration in Laboratory*, *36*(5), 93–96. doi: doi:10.16738/j.cnki.sjg.2022.05.066

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