Construction and Practice of First-Class Courses on Virtual Simulation Experimental Teaching of Urban Overpasses

Jun Lin*, Dingyuan Luo, Taotao Gao

Chongqing Institute of Engineering, Chongqing 400056, China

*Corresponding author: Jun Lin, linjun3215@139.com

Abstract: Virtual simulation experiment, as a new way to promote the digital transformation of education, has a broad development prospect and application value. The civil engineering experimental volume and space are huge, it has a long construction period, is highly dangerous, and is difficult to experiment with. In order to solve the contradiction between the traditional theory teaching of civil engineering and the engineering training of students, the construction of virtual simulation experimental teaching courses with a high degree of realism, intuition, and accuracy can be used as a useful supplement and innovation of experimental and practical teaching. This paper takes the virtual simulation experimental teaching course of urban overpasses as an example, introduces the necessity and practicability of the course construction, and describes the experimental principle structure of the course, the simulation scene design, the experimental teaching process, the experimental method, etc. The course has achieved good application results, and it has been recognized as the first-class virtual simulation teaching course of the Chongqing Municipal Government, which provides certain references to the construction of the same type of courses in the civil engineering profession.

Keywords: Digital transformation of education; Virtual simulation experiment; Civil engineering; First-class course construction

1. Study background

In the Notice of the General Office of the Ministry of Education on the Construction of Demonstration Virtual Simulation Experimental Teaching Projects from 2017 to 2020, it is pointed out that "experimental teaching projects are the basic unit for colleges and universities to carry out experimental teaching, and the level of their construction directly determines the overall quality of experimental teaching." In 2017, the Ministry of Education began the identification work of the national virtual simulation experimental teaching projects. In 2018, "Experimental Space," a national virtual simulation experimental teaching project sharing service platform was officially launched, aiming to provide full-process support for various types of courses in experimental teaching based on course declaration service, with course sharing application as

the core, and focusing on the exploration of intelligent technology, and providing full-process support for the construction, sharing, and application of experimental teaching to provide full-process support services. In 2019, the Ministry of Education issued the Implementation Opinions of the Ministry of Education on the Construction of First-Class Undergraduate Courses (Teaching High [2019] No. 8), which explicitly included virtual simulation experimental courses in the sequence of first-class course construction, and required the completion of about 1,500 first-class courses of virtual simulation experimental teaching in the country to be identified [1]. In April 2022, Tsinghua University Research Institute of Education released the Research Report on the Digital Transformation of Higher Education Teaching, pointing out that the digital transformation of higher education is imperative. In October 2022, the report of the 20th Party Congress proposed to "promote the digitization of education, and build a lifelong learning society for all people, and a large country with a learning culture." In 2023, the Department of Higher Education of the Ministry of Education pointed out in its annual work highlights that it is necessary to deeply implement the strategic action of digitization, and shape a new advantage in the reform and development of higher education. From the above information, we can see that with the digital transformation of higher education gradually unfolding and with the gradual formation of comprehensive learning and lifelong learning situations, the virtual simulation experimental courses have become digital teaching resources construction [2].

As a traditional engineering discipline, the experimental teaching of civil engineering majors has the special characteristics of the industry:

(1) Huge experimental volume and space: The service objects of civil engineering are buildings, bridges, and tunnels, and there are problems such as large volumes of experimental components and loading equipment, harsh experimental environments, and high experimental costs, which limit the participation of students.

(2) Long construction period: Due to time constraints, students' cognitive internships and production internships fail to include the experience of the whole process of engineering construction.

(3) Highly dangerous: Many civil engineering experiments are destructive tests, at the same time, due to the complexity of the construction site processes as well as students' lack of construction experience and the ability to identify sources of danger, the construction unit has safety concerns in the arrangement of student internship.

(4) Experimental difficulty: In the experiment of civil engineering, the simulation equipment for tunnel construction and bridge construction has a high cost. The excavation operation of a deep foundation pit is difficult, dangerous, and expensive.

In order to solve the contradiction between the traditional theoretical teaching of civil engineering and the engineering training of students, to provide students with opportunities for independent learning, personalized learning, and experimental operation, to stimulate students' innovation and practical skills, to expand the depth and breadth of experimental and practical teaching, and to improve the effectiveness of experimental teaching, it is necessary to use professional simulation software, multimedia technology, and network communication platforms to build the simulation equipment with a high degree of realism, intuition, and accuracy, as a useful supplement and innovation to the physical experimental and practical teaching [3].

2. Introduction to virtual simulation experiments

2.1. The necessity and practicality of the experiment

With the rapid urbanization in China, traffic congestion has become one of the main problems in urban development. At key road intersections, the installation of ground-level vehicle passages transforms

intersections into interchanges. This allows vehicles on main roads to pass quickly through the intersections, improving intersection capacity, significantly reducing travel time, and enhancing road safety. It is an effective way to alleviate traffic congestion and is also an important part of urban infrastructure development. Developed into a virtual simulation experiment with this background, its necessity and practicality are reflected in the following aspects:

(1) Through the development of virtual simulation experiments closely related to the development of the discipline industry and urban infrastructure construction projects, we have built a bridge between students and advanced technology and major engineering practice, realized a seamless connection between experimental teaching and cutting-edge technology and engineering practice, and provided important support for the cultivation of civil engineering professionals.

(2) The construction period of urban overpasses is long, and it is difficult for students to learn the whole process of tunnel construction systematically in a short period of time. Carrying out practical teaching based on actual projects allows students to have a good sense of experience and a high degree of participation, but it involves a large-scale and complex construction operation environment, long-period experimental observation, and high safety risk, which is not suitable for the development of the physical field.

(3) Urban overpass construction integrates "civil engineering construction technology and organization," "road survey design," "roadbed pavement engineering," and other courses, the pit excavation, geotechnical support, the main structure of the construction, roadbed filling, pavement paving, and other knowledge units in tandem, to solve the articulation between the basic theoretical knowledge and the actual engineering, and to improve the practical teaching system of the course [4].

2.2. Experimental principle and simulation scene design

As an important part of urban roads, a three-dimensional intersection has the characteristics of importance, complexity, enormity, and regionality compared with other structures. This experiment is a virtual simulation experiment of the whole construction process of the node reconstruction project of the planar intersection transformed into a rhombic intersection (underpass of the vehicular ground channel), which integrates the immersive cognitive experience, application of professional knowledge, training of engineering thinking, application of specifications and comprehensive cultivation of abilities, and realizes the enhancement of the students' knowledge and abilities in a diversified and progressive manner.

The experiment is based on the whole process of the construction of the overpass to develop simulation scenarios, a total of 20 interactive steps are set up, and the target requirements and assignment model are shown in **Table 1** below.

Table 1. List of experimental goal requirements and assignment models

Step	Step objective requirements	Step reasonable time	Goal attainment scoring model	Step score	Achievement types
1	**Project awareness:** Compare and contrast the modeled scenarios before and after the retrofit to understand the design concept of the diamond interchange (mainline underpass).	5	Simulation model viewing	—	ROperation grade RLab report RPre-test grade RInstructor evaluation report
2	**Discriminate intersection types:** Determine the type of intersection before and after the project is retrofitted.	5	Multiple-choice question set	5	
3	**Learning of basic knowledge:** Review the knowledge units and standard specifications provided by the system to complete the basics.	15	Knowledge learning	10	
4	**Determine the traffic road reconstruction plan:** Select a reasonable traffic organization scheme during construction and understand the design concept of traffic diversion.	5	Multiple-choice questions Model interaction	3	
5	**Read pit support design overview:** Read pit support design documents to extract valid information.	5	Information access	—	
6	**Foundation pit slope excavation support assessment:** To understand the main working principles of anti-slip piles and gravity retaining walls.	10	Multiple-choice question setting	5	
7	**Slip-resistant pile construction simulation interaction:** Master the process of anti-slip pile construction and familiarize with the sequence of construction.	10	Model interaction	5	
8	**Retaining wall construction simulation interaction:** Master the construction process of gravity retaining wall and familiarize with the sequence of construction.	10	Model interaction	5	
9	**Recognize the composition of retaining wall structure:** Recognize the structural components of gravity retaining wall.	10	Operation of drop-down selection	10	
10	**Foundation pit excavation construction simulation interaction:** Master the steps of foundation pit excavation construction, and familiarize with the design principle of foundation pit excavation and support while excavating.	15	Model interaction operation	5	
11	**Calculate the elevation of the opening of the access to the interchange:** Master the relevant provisions in the specification and the relationship between the elevation parameters of the main structure.	10	Data calculation settings	5	
12	**Interactive selection of ground channel limit design:** Be able to design reasonable building limits according to the code standards.	10	Engineering literacy settings	5	
13	**Determine the selection of reinforcement bars in different parts of the building;** Familiarize yourself with the requirements for the arrangement of reinforcement bars and improve your engineering literacy skills.	5	Engineering literacy settings	5	
14	**Construction simulation interaction of ground access main structure:** Familiarize with the composition of the main structure of the underground passageway and the construction process of the structure.	10	Model interaction	5	
15	**Selection of backfill material for roadbed:** To understand the requirements of different areas of backfill for wall backfill.	5	Model interaction	4	
16	**Selection of backfill compaction machinery:** To be able to select the appropriate construction machinery according to the construction workspace.	5	Model interaction	4	
17	**Selection of compaction standards for roadbeds:** Be able to query the specification and know the compaction standard of different parts of the roadbed.	5	Model interaction	4	
18	**Interactive simulation of road subgrade construction:** Master the construction machinery, compaction methods, and compaction standards of road subgrade.	10	Comprehensive application settings Model interaction	10	
19	**Simulation of road surface pavement construction:** Be able to equip suitable compaction machinery for 3 different construction stages: initial compaction, re-compaction, and final compaction.	15	Comprehensive application settings Model interaction	10	
20	**Completion of experiment, checking the experiment report:** After the experiment is finished, the system will automatically generate the experiment report, and reflect and summarize with the feedback of the report.	15	Checking the experiment report	—	

3. Experimental teaching process and experimental methods

3.1. Experimental teaching process

On the simulation platform, the virtual simulation experimental teaching is set up with three system modules: project cognition, knowledge learning, and virtual construction training, and clicking on each module can enter the corresponding simulation interactive link.

The experiment adopts multi-stage, multi-module, step-by-step experimental teaching, so that students learn from theory to practice, based on the task-driven, step-by-step urban overpass engineering practices, including basic theory learning, experimental operation training, experimental assessment, and feedback of the three experimental teaching links.

3.1.1. Basic theory learning

(1) Project cognition: Students click on the project cognition module to enter the operation scenarios before and after the project implementation, to realize the cognition and mastery of the background knowledge and theoretical knowledge of the project of Two Rivers Boulevard crossing Huanghu Road, and lay the theoretical foundation for improving the ability to solve practical engineering problems.

(2) Knowledge learning: Students need to complete the pre-study of experimental content in the system module before the experiment, and can only conduct the experiment after passing the examination. The module is embedded with important provisions of the "Urban Underground Road Engineering Design Code (CJJ 221-2015)," "Urban Road Roadbed Design Code (CJJ194-2013)," and other norms and technical standards to help students understand the experimental principles and methods.

3.1.2. Experimental operation training

Students click on the virtual construction training module to enter the three sub-modules of pit excavation and support, ground channel main structure construction, and pit backfill and roadway appurtenances. The system adopts fault-tolerant and exploratory experimental teaching methods, which allow students to interactively operate the various construction processes and select materials and mechanical equipment many times. In this training process, students are strengthened to construct engineering thinking of theoretical cognition, simulation verification, and iterative optimization, which lays a practical foundation for their ability to solve practical engineering problems in the future.

3.1.3. Experimental evaluation and feedback

After students complete the virtual construction training, the system will judge each operation step and generate the experimental report, which can not only effectively evaluate students' mastery of the specific construction process, but also allow students to optimize the design according to the system's judgment and master the management and visualization of the construction process and key parameters of the urban overpass through the case study to enhance the innovative ability of applying the knowledge to solve the actual engineering problems.

3.2. Experimental teaching methods

In the process of simulation experiment teaching, in order to strengthen students' understanding and mastery of knowledge, the scientific observation method, comparison method, research method, model method, deduction method, induction method, and other experimental methods are comprehensively applied in the three experimental teaching sessions, and the typical applications are as follows.

3.2.1. Scientific observation method

The system carries out a high degree of restoration and panoramic simulation of the construction scenes of the current intersecting roads Liangjiang Avenue, Huanghu Road, and their surroundings. In the virtual scene, students use the mouse and its pulley to rotate and zoom 360° on the road and all kinds of terrain models for scientific observation, which, combined with the learning of theoretical knowledge, initially forms a general overview of the project construction and the perception of the construction site environment.

3.2.2. Comparison method

In the project cognitive link, through the comparison of node transformation before and after the completion of the scene, students understand the design concept of the diamond-shaped interchanges, the initial determination of the project after the construction of the impact on the status quo traffic, the formation of the experimental results of the prediction.

3.2.3. Research method

In the experimental pit excavation and support simulation training, students obtain pit excavation methods, engineering geological conditions, construction technology standards, and other information through research, comprehensive analysis, and judgment; a comprehensive understanding of the ground channel pit support design ideas and technical standards can provide a basis to carry out the construction of pit support construction simulation interactive operation.

3.2.4. Modeling method

The realistic three-dimensional simulation model restores the construction process of the underground passageway, visualizes the processes and scenes of pit excavation and support construction, main structure construction of the underground passageway, and pit backfill and roadway appurtenances construction, which is conducive to students' intuitive cognition and understanding of the application, and solves the teaching problems.

3.2.5. Deduction method

In the simulation training of the construction of the main structure of the ground channel, students need to analyze the vertical elevation and structural thickness of the ground channel, think about the factors affecting the design elevation of the road surface under the road; and after logical projection, they make a reasonable selection of parameters such as the design elevation of the road surface of the intersection layer, the thickness of the overburden, the thickness of the structural roof of the ground channel, and the headroom height of the carriageway.

3.2.6. Generalization method

After the students complete the virtual construction training, according to the evaluation of the experimental report and analysis of relevant data, combined with the various operational steps of the virtual simulation experiment of urban overpasses, the basic principles and methods are summarized to recap the intrinsic inevitable connection between the various construction processes.

4. Experimental teaching characteristics

4.1. Realizing the connection of knowledge of multiple courses and embodying the continuity and completeness of practical teaching by solving actual engineering problems

The experiment has the characteristics of comprehensive, practical, and innovative, and contains three modules

of pit excavation and support, main structure construction, and roadbed and pavement ancillary engineering construction in construction training, corresponding to the important knowledge points of many courses, such as "Foundation Engineering," "Tunneling and Underground Engineering," and "Roadbed and Pavement Engineering," etc., which are linked together through the experiment to solve the actual engineering problems in the simulation experiment, reflecting the continuity and completeness of practical teaching. Taking the roadbed and pavement subsidiary construction module as an example, the module involves the understanding of the project's roadbed and pavement structural composition, the selection of compaction machinery, paving machinery, and materials, and the determination of the compaction degree of the roadbed and pavement paving thickness.

4.2. Relying on the actual construction scene of the project for virtual simulation to achieve the associated optimization of the construction process based on the scene

The experiment is developed based on the real data of the node project of Liangjiang Avenue and Huanghu Road, a key municipal construction project, and 3D virtual simulation modeling is carried out, which realistically restores the construction scene. Students operated the system through computer terminals, reproducing the whole process of the project from pit excavation, retaining wall support, and main structure construction, to roadbed backfill and pavement paving, and reflecting the mutual influence and logical relationship of each construction link through operational feedback. Virtual simulation technology means to solve the difficulty of organizing in-person practice at large-scale engineering construction sites, and the whole process of tracking the disadvantages of the project implementation, eliminating the adverse effects of on-site practical teaching in time and space.

4.3. Establishment of the "project cognition + theoretical learning + construction simulation training" modularization, progressive teaching mode, theory and experimental combination, and integrated evaluation system

When students enter the experiment, they first enter the project cognition module. After fully understanding the ground channel, they understand the basic overview of the project, interoperability applications, and program design concepts, and then enter the knowledge learning module to construct project content, technical specifications, process learning, etc.; after completing the test, the teacher will provide supplementary explanations on the difficulties in the experiment based on the test and finally enter the construction simulation training. Through the simulation technology and teaching design, the experiment prompts students to carry out active knowledge construction, establishes a multi-level, progressive teaching mode, and carries out assessment and evaluation from both theoretical and experimental aspects. As the main part of the experiment, the construction simulation training will record the interaction operation of the students in the simulation construction process of the overpasses in real time, and the students will adjust the construction program in time according to the conclusions of the system feedback and error correction prompts, and the background of the system will synthesize the engineering standards and safety indicators to dynamically evaluate the students' design inputs, and complete the process of assessment. The experimental system is based on the urban interchange project under construction, reproducing the key construction steps through digital means, each process corresponds to the interactive operation of students, and the background of the system calculates the degree of achievement of the course objectives based on the completion of the construction process, which is used for closed-loop feedback and continuous improvement.

5. Effectiveness of course application

The opening of the "virtual simulation experiment of urban overpasses" is in line with the current digital

transformation of education and the development trend of experimental teaching, and the application of simulation and interactive scenes has a very important demonstration and intuitive experience value for the understanding of the design concept of urban road interchanges, the construction sequence of the open-cut ground channel, and the construction process. After the simulation experiment training, students' independent learning ability and engineering practical skills have been significantly improved. At present, the course is open to colleges and universities and the public in the Zhihuishu platform, and access to the virtual simulation experimental (training) teaching project sharing platform in Chongqing colleges and universities, the course has gone through two teaching cycles of construction and operation, the experimental browsing volume of more than 2,500 times, the number of applications of more than 430 people, the course was successfully recognized in November 2023 as a first-class course in Chongqing (virtual simulation experimental teaching courses). In the future, the course team will continue to improve this virtual simulation experimental system, enhance the integration and sharing capacity of quality teaching resources, and open up new ways for the cultivation of civil engineering professionals.

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Disclosure statement

The authors declare no conflict of interest.

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