Learning Outcomes of Civil Engineering Students in PBL Based on Building Information Modeling

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Abstract—The new technology called building information modeling (BIM) derived in China's construction industry in the general background of information era, as well as construction of intelligent buildings and smart cities, requires many university students majoring in Civil Engineering who are skilled in BIM technology. Characterized by online learning at any time, free and diversified learning modes, and ubiquitous learning, project-based BIM teaching can effectively improve the learning outcomes of Civil Engineering majors. To explore such learning outcomes of these students from engineering technological universities from project-based BIM teaching, 240 junior students majoring in Civil Engineering from 4 universities in Henan Province, China were chosen as research objects (120 each for the control and 120 experimental groups). The effect of BIM teaching in improving learning outcomes was investigated through a 16-week teaching experiment of *Design Theory for Concrete Structure*. The experimental and control groups used the project-based BIM teaching and traditional teaching modes, respectively. On this basis, independent and paired sample T-tests were carried out to the experimental data. Research results showed that pre-test scores of the group and control groups have a normality trait, conforming to the preconditions of the teaching experiment. Pre- and post-test scores of the experimental group had evident differences. Post-test scores of the experimental group were 15.82 higher than the pre-test scores, and the difference had statistical significance ($P < 0.001$). Owing to BIM teaching, post-test performances of the control and experimental groups also had significantly statistical significance. Project-based BIM teaching can improve learning outcomes of university students majoring in Civil Engineering. Research conclusions have important references to build BIM teaching resource platform, solve scattered and insufficient BIM teaching resources, facilitate active learning of university students majoring in Civil Engineering, and improve teaching effect.

Keywords—project-based teaching, BIM teaching, students majored in civil engineering, learning outcome, teaching experiment

1 Introduction

In the general background of the increasingly extensive applications of "Internet +" and information technology (IT) in the construction field, students majoring in Civil Engineering in engineering technological universities can still substantially improve in terms of comprehensive talent training. Education quality improvement is influenced by learning engagement, and China advocates facilitating education reforms through project-based teaching. Given that project-based teaching is implemented through cooperation and participation, learning engagement has attracted relative attention. The learning quality of students majoring in Civil Engineering in engineering technological universities is of high concern, and their learning engagement may relatively influence learning quality. In the new era of China, civil engineering has become one of indispensable majors for the country's economic development. China's construction industry is facing a new stage of high-quality development. In particular, smart cities and intelligent buildings require more civil engineering professionals who can efficiently use building information modeling (BIM) technology. Owing to 3D visualization and strong coordination, BIM technology can effectively imitate specific processes of building construction, and it plays a considerably important role in the design, construction, operation, and other links of civil projects. Accordingly, improving the construction efficiency of the architectural industry is a key technological reform to change the civil engineering industry. Although China has comprehensively built a policy environment for BIM construction, BIM technology has not been extensively applied in the country owing to lack of professionals, narrow application spaces, and few competitive construction projects. Therefore, technological universities in China must immediately train a group of talents skilled in BIM technology to achieve matching between talent training scale of civil buildings and industrial development, as well as help most enterprises to address shortages in BIM-related professional technicians and talents.

BIM teaching aims to integrate specific practical teaching projects into teaching activities, and project-based BIM teaching can generally improve the learning motivations of learners, thereby meeting learning demands. Although traditional teaching modes can relatively help students learn knowledge of BIM, it is disadvantageous for the long-term development of students. Teachers take the dominant role in teaching, and students can only receive knowledge and contents taught by teachers passively, eventually making them lose interest in BIM learning. More extensive applications of project-driven BIM teaching by teachers in universities and colleges better conform to the learning mode of current university students, who can take a dominant role in classrooms. Students discover, analyze, and solve problems positively, which can improve their learning interest and enthusiasm. In project-based BIM teaching, teachers can implement project-based reform toward specific teaching contents of BIM, so that students are markedly interested in learning content, and teaching quality of teachers is improved accordingly. Project-based BIM teaching requires teachers of specialized civil engineering courses to determine teaching contents before each class and fully definite teaching program by combining textbook contents and the practical learning situations of students. By choosing project-based BIM teaching, teachers can encourage students to improve their abilities to solve specific problems in civil construction and their comprehensive quality. Lastly, adopting different teaching strategies to students of different levels is conducive to adjusting the personalized learning programs of students and improving their learning outcomes.

2 Theoretical basis and literature review

2.1 Theoretical basis

Constructivism learning theory was first derived from the children's cognitive development theory of Piaget. Bada, S. O et al. [1] believed that constructivism can explain cognitive laws of individuals during the learning process. This theory emphasizes that students are protagonists in a class, while teachers shall design teaching activities in favor of meaningful construction of students, organize them to communicate and discuss, and create scenarios and provide various learning resources to students. Research during teaching design and implementation shall be designed by combining with relevant principles proposed by constructivism learning theory. Students can be divided into several groups according to their willingness and relevant grouping principles, which is conducive to strengthening their cooperation ability. Teachers shall design independent exploration activities for students, so that the latter can establish and form their own understanding of knowledge through independent exploration and group discussion. In class, teachers shall guide students to make timely reflections on and summaries of their problems or those of the group, develop process assessment, and correct problems in a timely manner. Teaching activities, such as team cooperation and process assessment, can improve the learning engagement of students in project-based teaching.

Multiple intelligence theory was proposed by Gardner, H et al. [2], and it is an important theoretical basis of the current study. Multiple intelligence theory believes that on the conceptual level of students, each student has different abilities, and students may have varying abilities owing to differences in various aspects. That is, everyone may present unique ability advantages. Teachers shall fully understand and respect such differences in abilities of students during teaching, view their students deeply, and encourage them at appropriate times, so that students can develop their strengths and achieve a sense of satisfaction. On the conceptual level of teachers, multiple intelligence theory deems that teachers shall determine accurate teaching objectives according to practical situations. However, this situation does not mean that all students can be trained to become comprehensive talents; it implies that teachers shall formulate learning direction to students according to their abilities and help every student develop in accordance with their respective specialties. Attention shall be given to the development of students and literation of personality. In addition, it emphasizes more on diversified learning of every student and development toward "diversified learning, diversified teaching." In particular, it highly emphasizes on group cooperative discussion and learning, and training of students' interpersonal skills. Multiple judgments on after-class self-reflection of students shall be given as much as possible to guide the more comprehensive development of their abilities.

2.2 Literature review

Project-based teaching is a student-oriented teaching mode that advocates learning, has close relation with daily life, and focuses on students' mastering actual skills. It has been widely applied and promoted globally. In the background of "Internet +," relevant applications focus on how to meet the learning needs of different learners through online project-based teaching. Project-based teaching content is divided into several modules, and relevant knowledge points are updated for consistency with present industrial development needs. Some studies have investigated the influences of project-based teaching and BIM teaching on learning outcomes of students. Kokotsaki, D et al. [3] indicated that project-based learning (PBL) is a positive student-centered teaching mode that can guide student learning and provide them with effective guidance and support. Grossman, P et al. [4] believed that PBL is successful, and project-based teaching is beneficial in developing a classroom culture of production, feedback, reflection, and correction. Lasauskiene, J et al. [5] reported that PBL guides transition from teaching techniques to interactive learning, including preparation and demonstration of projects. Project-based learning strategies and methods must be used as among the most basic means of higher (self) education to train the project activity abilities of students (orienting to music teachers in the future). Hasni, A et al. [6] found that project-based teaching is an innovative method of scientific and technological teaching. Beckett, G. H et al. [7] argued that project-based language teaching can train decision-making ability and independence and also strengthen cooperative working skills, challenge creativity, train creative thinking skills, and improve the problem-solving abilities of students. Fragoulis, I et al. [8] introduced the theoretical basis for PBL and proposed benefits for students to participate in projects. Lee, J. S et al. [9] investigated two teaching aspects of PBL in higher education environment and confirmed the teaching and learning significance of PBL as a teaching method. Okudan, G. E et al. [10] believed that project-based teaching can improve the satisfaction of entrepreneurship education and students' opinions of the course. Sari, I. A. U. W et al. [11] found that project-based teaching can improve the learning motivation and outcome of learners. Hosseinzadeh, N et al. [12] discussed the advantages and disadvantages of PBL in courses for students majoring in Power Engineering, and concluded that PBL can provide technological contents and general professional skills in specialized courses. de Los Rios, I et al. [13] proposed teaching method of cooperation project-based learning and found that it promotes the training of skills, individuals, and context ability; and facilitates collaborative learning by integrating teaching and studies. Sababha, B et al. [14] demonstrated that student feedback proves the validity of the teaching method of cooperative project-based learning in improving the understanding and ability of students to solve practical engineering problems by suing the embedded system design concept. Hugerat, M. [15] showed that science students who use project-based teaching strategies achieve significantly higher satisfaction and pleasure to the classroom atmosphere than other students. Adamu, Z et al. [16] reported the strategic methods applied by large multidisciplinary universities for civil and architectural engineering. They found that BIM teaching can improve knowledge, intelligence, and practical and transferable skills of Civil Engineering majors. Puolitaival, T et al. [17] believed that BIM teaching is an important way for teaching civil engineering reform. Peterson, F et al. [18] was convinced that BIM-based project enables learning of the local optimization of project plans, and suggested to adopt BIM teaching in education programs for training architectural engineers. Sotelino, E. D et al. [19] believed that BIM teaching can improve the learning motivation of young professionals and has evident influences on their learning outcomes. Abbas, A et al. [20] presented the status of BIM education in Pakistan's universities and proposed specific measures to improve BIM teaching in civil engineering. Kim, J. L [21] indicated that BIM education is beneficial for students in effectively learning construction details and material amount. Agirbas, A [22] found that when BIM is combined with the teaching of Basic Architecture, which is a course in architecture degree programs, student can understand the principle of building system in a simple and effective manner. Becerik-Gerber et al. [23] explained that introducing BIM to the virtual cooperation environment enables teachers to design a course by combining more practical scenes, thereby enabling them to better simulate real-world challenges. Wu, W et al. [24] demonstrated that BIM teaching can facilitate Civil Engineering majors to improve learning outcomes through self-study. Wu, W et al. [25] emphasized the collaborative application of BIM in mini-solar energy housing project. Results showed that BIM teaching could promote students to learn BIM knowledge positively and train their comprehensive problem-solving abilities from design to construction. Hu, M [26] believed that BIM supporting teaching method was developed and tested in building materials and construction techniques courses, and found it was more effective than the traditional teaching mode. Succar, B et al. [27] believed that individual abilities of BIM had brought many benefits to the industry and academic circle. Lee, P. C et al. [28] invited 20 students to a learning community of fabricated architectural design and found that the proposed BIM embedding knowledge-sharing platform and learning community mode are beneficial to improve learning outcomes. Suwal, S et al. [29] analyzed the perception and emotions of 57 students in using an online BIM learning platform. Results showed that the online BIM learning platform is highly viewed as a positive learning experience by students. Chen, K et al. [30] proved that BIM teaching and teaching design play important roles in the experiences of learners to improve learning courses and enhance learning outcomes with stronger learning motivation. The preceding literature review indicates that BIM technology is an essential result of the rapid development of the construction industry and smart city development, and traditional architectural design modes cannot meet the needs of the development era. BIM technology can accelerate the development of the construction industry owing to 3D visualization and one-day working. Hence, BIM technology is welcoming increasing social needs as a new skill and it is becoming a new highlight and trend of talent needs in China's construction industry. Accordingly, there are multiple aspects and multiple levels of demands for BIM talents. Hence, reform and the establishment of BIM courses in universities should be accelerated, and BIM ability training for university students majoring in Civil Engineering must be popularized and strengthened. Moreover, an essential channel for teaching reform and comprehensive talent training reform in civil engineering departments in universities is that teachers shall integrate the entire process of BIM simulation project construction and BIM course teaching, as well as improve learning outcomes of learners through practical case analysis.

3 Methodology

3.1 Respondents

Henan is a province in China with a large economic population and has witnessed rapid urbanization in recent years. Accordingly, there is a tremendous demand for civil engineering graduates. Project-based BIM teaching reform also becomes a key content in professional teaching reform of civil engineering in many universities in Henan. In this study, 240 junior students majoring in Civil Engineering in Zhengzhou University, Henan University, Institutes of Technology of Henan, and Yellow River Traffic Institute in Henan were chosen as research objects. An experimental study based on the *Design Theory for Concrete Structure* course was carried out. The research objects were divided into experimental and control groups. Among the 4 universities, 2 were chosen as the experimental group, with 120 students (105 males and 15 females), while the other 2 were chosen as the control group, with 120 students (105 males and 15 females). Teachers adopted the project-based teaching method to students of the experimental group to stimulate their learning interest on BIM and make reasonable uses of all effective teaching resources. By contrast, the traditional classroom teaching was applied to the control group, without any treatment. Whether or not BIM teaching can improve the learning outcomes of students majoring in Civil Engineering in engineering technological universities in the background of project-based teaching was investigated through a comparative study of the experimental and control groups.

3.2 Research scheme

The present study performed variable selection, measurement, and control for education experiment. First, pre-test scores of student number and learning ability of the experimental and control groups were analyzed. Before the experiment, the original basis of both groups were tested and comprehended through a pre-test to control for irrelevant variables. Second, the students were randomly divided into two groups according to their comprehensive performances in the second semester of their sophomore year, thereby assuring no evident differences between the two groups in terms of learning abilities. Third, the experimental group used the BIM teaching method, while the control group used the traditional teaching mode. A 16-week teaching experiment of the *Design Theory for Concrete Structure* course was implemented. The students reviewed the knowledge they learned in the 17th week and had a written exam in the 18th week. The final exam scores of the students were used as variables of learning outcomes.

4 Results analysis

4.1 Pre-test result analysis

A statistical analysis of the comprehensive performances of students in the second semester of their sophomore year was performed before project-based BIM teaching. The results are shown in Table 1.

Table 1. Pre-test scores of the experimental and control groups

Samples	Mean	Standard Deviation (SD)	Mean Standard Error (MSE)	T Value	P Value
Pre-test scores: experimental group	63.19	2.86	0.26	−0.71	0.481
Pre-test scores: control group	63.45	2.66	0.24		

Table 1 shows that the mean pre-test scores of the experimental and control groups only present a difference of 0.26, indicating that students of the two groups have approximately the same performance levels. That is, the students' mid-term performances are similar. According to independent sample T-test of the pre-test scores of the experimental and control groups, P-value of 0.481 (>0.05) indicates no statistical significance between the two groups in terms of comprehensive performances in the second semester of their sophomore year. That is, performances of two classes were insignificant, and no evident differences exist between the two groups. Hence, the comprehensive performances in the second semester of the sophomore year can be used as pre-test scores of this teaching survey. Teaching practices can implemented in the two groups, meeting the preconditions of the teaching experiment. Distribution statistics of pre-test scores of 240 students was implemented by the SPSS 26.0. A histogram of normal distribution was plotted (Figure 1).

Figure 1 shows that the pre-test scores of the 240 students generally present a normal distribution, and a normality test was further performed using SPSS 26.0. Given that the sample size is above 50, the Kolmogorov–Smirnov (K–S) test was chosen (Table 2).

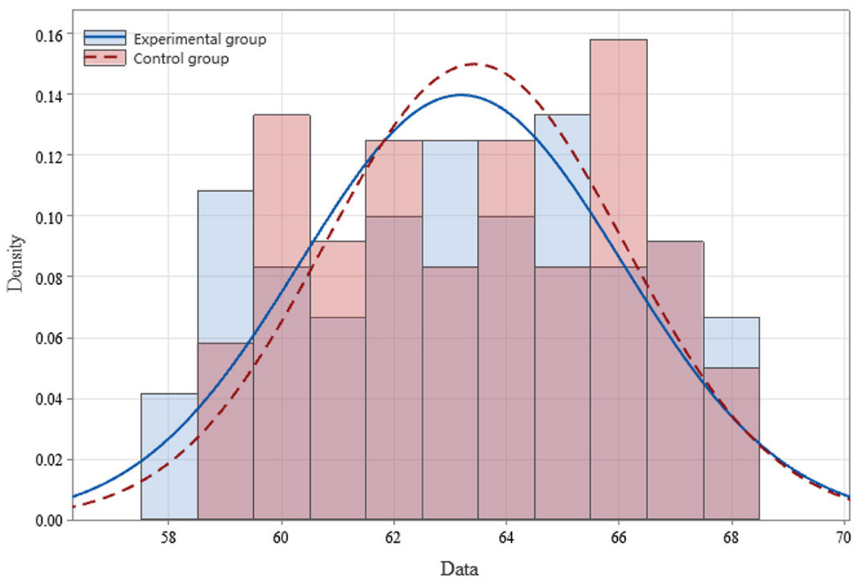

Fig. 1. Histogram of the pre-test scores of the 240 students

Table 2. Normality test of the pre-test scores between the experimental and control groups

Samples	K–S	P-Values
Pre-test scores: experimental group	0.069	0.150
Pre-test scores: control group	0.093	0.013

Table 2 shows that the P-values of the pretest scores of the experimental and control groups are above 0.05. This result implies that the pre-test scores of student have normality.

4.2 Paired sample T-test of the pre- and post-test scores of the experimental group

Table 3. Paired sample T-test of the pre- and post-test scores of the experimental group

Mean	SD	MSE	95% Confidence Interval	T-Value	P-Value
−15.820	1.780	0.163	(−16.142, −15.498)	−97.35	0.000

Table 3 shows that the P-value is below 0.01, indicating clear differences between the pre- and post-test scores of the experimental group. Post-test scores of the experimental group are 15.820 higher than the pre-test scores. This conclusion is true mainly because many engineering universities in China are currently using BIM teaching, and training of BIM application talents becomes a foothold in the comprehensive reform of civil engineering talent training. Civil Engineering majors in the four universities have established project-based BIM teaching team by professional teachers. Moreover, BIM course contents, particularly project-based teaching contents, have been optimized by transforming specific civil construction projects into BIM teaching contents, making students participate in teaching activities positively and improving the learning interest and endogenous power of learners. The project-driven teaching mode conforms substantially to the learning needs of current students majoring in Civil Engineering. University students assume the dominant role in classroom teaching through learning groups, mutual discussions, and other methods. Students can discover problems positively and develop abilities to solve problems in specific teaching activities of BIM, accompanied with significant improvements in learning interest and learning enthusiasm. In BIM teaching settings, teachers can maximize various teaching resources of civil engineering, such as BIM teaching tools and BIM specific construction cases, to meet the learning needs of learners at different levels and to improve their professional skill levels. Research conclusions also prove that BIM teaching can improve the teaching effect. This result is consistent with the conclusions of most studies.

4.3 Difference analysis of post-test scores between the control and experimental groups

Table 4. Difference analysis of post-test scores between the two groups

Samples	Mean	SD	MSE	Difference	95% Confidence Level of Difference	T-Value	Degree of Freedom (DOF)	P-Value
Post-test: control group	67.40	3.58	0.33	−11.617	(−12.513, −10.721)	−25.55	237	0.000
Post-test: experimental group	79.01	3.46	0.32					

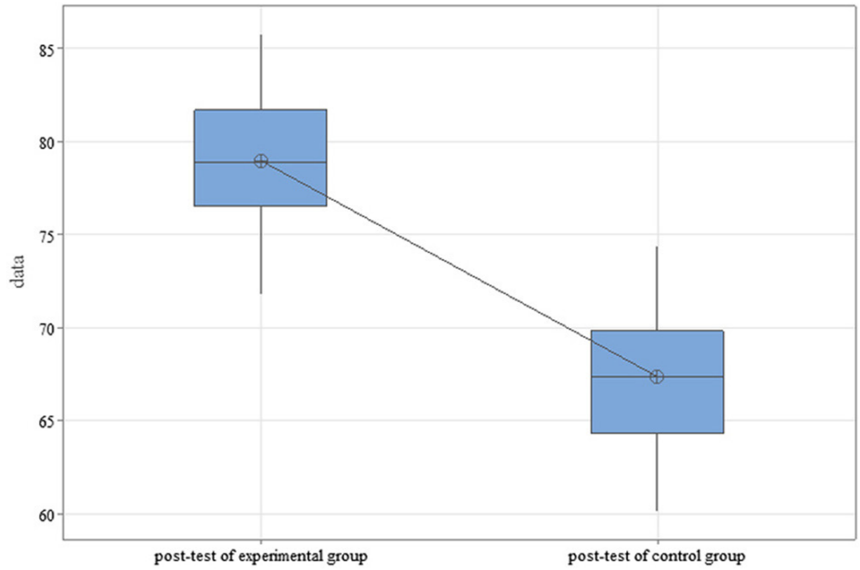

Fig. 2. Post-test scores of the control and experimental groups

Table 4 and Figure 2 show that the post-test scores of the experimental group are 11.617 higher than that of the control group, and the P-value is 0.000 (<0.001). This result reveals that BIM teaching brings significant differences in the post-test scores between the experimental and control groups. According to reason analysis, BIM teaching's advantage is that students can truly and directly participate in projects. This result plays an important role in improving the practical abilities and knowledge of students and can relatively stimulate their learning interest. In this period, students have to be equipped with some knowledge. During the selection and determination of actual projects, teachers shall choose the most reasonable project types by combining practical situations of the school and students, thereby enabling judgment of the project type and fully develop the advantages. Students are also urged to learn additional knowledge contents in projects and continuously improve their professional abilities and comprehensive qualities. Moreover, many universities may often adopt different modes in practical BIM teaching activities, encourage students to participate in projects, and continuously improve the implementation and teaching effects of projects. Teachers run through the course based on a project, and technicians from BIM enterprises are invited as part-time teachers to give students special lectures and some course contents. After the course teaching reaches a certain progress, real-project practice is performed in internship-based enterprises. The course is assessed through the completion of project tasks. This situation implies that students considerably focus on current hotspots in the civil construction industry, and the university-enterprise cooperation and project-driven teaching mode agrees with the target requirements of applied talent training.

5 Discussions

Professional talent training of civil engineering has different characteristics in different historical periods of China, and talent training modes in different periods are established based on adaptation to social development. Leon, I et al. [31] believed that BIM is a reform tool to promote the rapid development of the modern construction industry, and it has important values to improve construction efficiency in the construction industry. In the Internet background, the advantages of BIM teaching are fully developed. Scattered diversified teaching data are integrated into corresponding modules, and a BIM teaching resource platform is built for the convenience of effective access by different levels of students majoring in Civil Engineering and the relevant teachers. BIM teaching can meet internal learning needs at any time and any place. Civil Engineering majors can improve the application ability level of BIM knowledge through basic knowledge introduction, case analysis, and comprehensive application of BIM teaching (Peterson, F et al. [32]). Teachers are responsible for the high-efficiency maintenance of platform resource information through online teaching channels, integrate courseware materials, and optimize classroom teaching environment. In BIM teaching, teachers can introduce building and application of the BIM model based on a practical civil construction project. Students at different levels can acquire models of the same project in different stages from the module at any time and proceed to the next step. Students with different majors can operate on the same project model simultaneously, breaking barriers among majors and realizing interdisciplinary collaborative operation (Zamora-Polo, F et al. [33]). BIM teaching combines physical and network virtual classrooms. The network virtual learning space provides free learning, and the time, places, and contents for students to learn BIM are markedly flexible. BIM teaching allows fragmented learning and effectively addresses the limited class hours for classroom teaching (Li, X et al. [34]). Project-based BIM teaching has an extensive scope and immense advantages to the comprehensive ability training of students. Collaboration of project-based BIM teaching with other majors can understand basic contents, requirements, design thinking, and results of other majors, as well as solve technological problems caused by a single major. Project-based BIM teaching has reasonable division of labor during building design, make overall plans, coordinate and cooperate with other majors, and improve overall mastering and global thinking of the entire construction engineering design process (Keung, C. C. W et al. [35]). Moreover, many teachers and students participate in project-based BIM teaching. Students can improve team cooperation and interpersonal communication abilities in the process of graduation project. A suggestion is to choose some topics worthy of study and close to reality, give students real project training before graduation, and strengthen their practical abilities.

6 Conclusions

At present, BIM plays an irreplaceable role in the development of China's construction industry. Owing to the rapid civil construction industrial development in China, the demand for quantity and quality of graduates who major in Civil Engineering and skilled in BIM technology are is gradually increasing. Modularized BIM teaching shall be improved continuously in practices under "Internet +" to train more BIM technicians. Traditional BIM teaching can no longer adapt to learning and development of students. Hence, BIM teaching should innovate and be perfected, and can be integrated with project-driving teaching. This research conducted a comparative study based on the *Design Theory for Concrete Structure* course involving 240 junior students (120 in the control group and 120 in the experimental group) majoring in Civil Engineering from Zhengzhou University, Henan University, Institutes of Technology of Henan, and Yellow River Traffic Institute. The experimental and control groups use the project-based BIM teaching and traditional teaching modes, respectively. After a 16-week teaching practice, the influences of the project-based BIM teaching on the learning outcomes of learners are analyzed through independent sample and paired sample T-tests. Three major conclusions are drawn. (1) Pre-test scores of the experimental and control groups indicate that pre-test scores of students have normality traits. (2) Post-test results of the experimental group are 15.82 higher compared with the pre-test results. P-value is 0.000 (<0.001), proving the advantages of project-based BIM teaching. (3) BIM teaching brings evident differences in the post-test results between the experimental and experimental groups. Project-based teaching can help students to combine new and old knowledge positively and improve the learning outcomes Civil Engineering major. Lastly, this study suggests to make deep research on project-based teaching based on APT theory and prolong the teaching practice period in the future.

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