Journal of Engineering Science and Technology Review 15 (4) (2022) 140 - 145

Research Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Influences of Digital Twin Technology on Learning Effect

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Received 1 July 2022; Accepted 3 September 2022

Abstract

This study designed a questionnaire to investigate the influences of digital twin (DT) technology on ubiquitous learning effect based on the relevant theory. The influences of four subsystems (virtual-reality symbiotic system, information transmission system, intelligent control system and teaching support system) of DT technology on ubiquitous learning effect were analyzed. Results demonstrate that the overall Cronbach α of the designed questionnaire is 0.850, KMO is 0.785, and the corresponding P-value is 0.000, indicating the good reliability and validity of the questionnaire. All four subsystems (information transmission system > teaching support system > intelligent control system > virtual-reality symbiotic system) of DT technology have significantly positive influences on the ubiquitous learning effect. The obtained conclusions have important references to construct personalized DT learning space, facilitate construction of digital campus, accelerate deep integration of intelligent technologies into education reform, and promote personalized learning of learners.

Keywords: Digital twin technology, Ubiquitous learning, Learning effect, Regression analysis, Reliability, Validity

1. Introduction

With the extensive influences and depth application of the latest information technologies (e.g. mobile internet and 5G communication) in the education field, how to affect ubiquitous learning by the latest information technologies attracts wide attention. The digital twin technology projects objects in the physical world into the information world through digitalized representation so that information agents can exchange information conveniently. Educational modernization can be improved more quickly after the high-efficient integration of physical information and virtual information. DT technology is the link between physical devices and the information world, and it helps increase intelligent interaction between education equipment and education information. The ubiquitous learning effect has been improving unsatisfyingly because of the poor interaction of equipment in higher education teaching. However, DT can realize interaction among various education equipment so that the diversified and complicated education information can be used on a larger scale in man-machine interactions. DT technology can build a learning space, including learning subjects and educational information equipment. A personalized ubiquitous learning space facilitates deeper integration of DT plan with other information technologies to provide higher education productivity for the higher education reform, such as Maker Education and STEM project teaching. As a new technology in the tide of industrial 4.0, DT technology can offset shortages of many technologies (e.g., the Internet, VRAR, and big data) in virtual representation, and it brings fundamental changes in teaching and learning modes in higher education. In future learning scenes, DT technology can recognize learning state efficiently, monitor the whole learning process, make accurate prediction and effective assessment of learning performances, drive seamless teacher-student and student-student information exchange, and provide learners with more scientific and accurate learning experiences.

Given that DT technology can improve learning motivation and strengthen ubiquitous learning responsibility of students, it is conducive to the accumulation of professional knowledge, improving the ubiquitous learning effect. With real-time performance, strong interactive operation, strong expandability, and high fidelity, DT technology can easily create an integrated learning space in ubiquitous learning, realize the high-efficiency integration of physical and virtual learning spaces comprehensively, effectively facilitate changes in teaching mode, and develop new learning habits of ubiquitous learners. Through real-time acquisition and analysis of multi-dimensional data of teachers, learners, and physical equipment, DT technology can analyze the learning needs of different physical subjects and then allocate public teaching resources of universities flexibly and efficiently according to needs. Besides, DT technology can build a more efficient learning space without spatial and temporal constraints over ubiquitous learning and give different learners good learning experiences and interactive, cooperative, and explorative learning. DT technology also can provide a perfect learning space to train the core abilities of learners and help them accumulate key knowledge. DT technology can bring better learning experiences, enhance deep learning and high-order abilities of learners, and finally improve the ubiquitous intelligent learning effect comprehensively and efficiently.

2. Hypotheses development

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ISSN: 1791-2377
doi:10.25103/jestr.154.20

2.1 Theoretical basis

Weiser, M [1] believed that ubiquitous learning is a future learning mode in the computing environment as a result of the development of high-efficiency computing technologies and global computer and supporting network development. It is a mainstream lifelong learning mode for individuals. Without spatial and temporal constraints, ubiquitous learning allows learners to learn at different places and times. The information acquisition is going to be more efficient and transparent. Yang, S. J [2] believed that educational institutions should create a good ubiquitous learning environment for learners, especially in higher education. The reason is that university students are apt to self-study, make real-time adjustments to learning plans, choose appropriate learning content, and realize high-efficiency allocation of learning resources. Ubiquitous learning requires learners to formulate a good learning activity plan and a good learning schedule. Higher educational institutions must build a multi-dimensional platform integrating various physical equipment and information technologies for learners, which is conducive to learning reflection and improving the academic performances of learners. Thus, learners are more willing to accept the ubiquitous learning mode and develop a good habit of lifelong learning.

DT technology is conducive to improving the ubiquitous intelligent learning effect. It arouses strong learning motivation and learning interest of learners by establishing a series of ubiquitous learning resources and learning activities. Moreover, DT technology responds to learners' personalized learning demands by using more knowledge and experiences in a cross-media and unstructured way. Teachers guide students to make personalized knowledge exploration and improve technological application in the ubiquitous intelligence space rather than focusing on spreading the knowledge object and students' understanding and digestion. Learners may have the corresponding DT, and the combination of the learning community also may be expanded to contain various subjects, such as learners, learner twins, and even intelligent machines. New connotations will be given to intelligent group cooperation.

2.2 Hypotheses development

Many studies have reported how DT technology influences the learning effect. Liljaniemi, A et al.[3] pointed out that DT technology is a key technology related to industrial 4.0. In engineering education, it can provide new knowledge to students, teachers, and enterprises and improve learning motivation and learning outcomes using new digital technologies. Jones, D et al.[4] made a more systematic review of the DT technology and summarized characteristics and knowledge of DT. Kalansooriya, P et al.[5] pointed out that a three-dimensional holographic technique can interact with remote audiences and is a good remote learning technology. He assessed the effectiveness of the three-dimensional holographic technique in remote learning. Nikolaev, S et al.[6] studied classical methods to strengthen system engineering in the digital environment, developed an MSc-level course, and created the latest practices in innovative product design based on real cases. Kinsner, W [7] believed that DT system can be a new personalized education system and can realize flexible learning and effective interaction. Sepasgozar, S. M [8] proposed a set of five new digital technologies, innovated a new immersive building block, and practiced the digital teaching method by representing the usefulness of virtual reality (VR), augmented reality (AR), and DT technology in teaching activities of architectural courses. The study exhibited the applicability of VR in education. Verner, I et al. [9] replaced the physical robot experiment with a virtual twin robot simulation and disclosed its potential in teaching activities to first- and fourth-year high school students and teachers. Keaveney, S et al.[10] argued that an application which allows data record and transmission to AR based on the cloud platform could be developed through the DT technology. The industrial 4.0 practical application pilot training plan for undergraduates and industrial trainees has proven the effectiveness of integrating different digital technologies in the teaching effect. Luo, S [11] proposed a VoT model, which uses the idea of DT technology. Results demonstrated that DT technology has higher efficiency than similar technologies in students' educational effectiveness. Zacher, S [12] believed that DT technology is a software model. The advantages and disadvantages of DT technology in engineering education were discussed.

With respect to ubiquitous learning outcomes, Chen, C. C et al.[13] built a ubiquitous learning system (CAULS) to test and assess the real learning behaviors of students. Results showed that such a ubiquitous learning system could improve students' learning willingness, and most students increased their test scores significantly. Liu, T. Y et al.[14] proposed an education resource universal learning environment (EULER) based on radio frequency identification, AR, Internet, pervasive computing, embedded system, and database technology. Results showed that EULER improved the learning of students. The effectiveness of EULER in supporting outdoor learning was proven. The u-learning environment built by Hsieh, S. W et al.[15] increased the reflection level of students significantly. Furthermore, he suggested matching the learning style of students and the appropriate teaching style. Ogata, H et al.[16] introduced a method which helps learners to record learning experiences in daily life from a life log using SenseCam and pointed out that such ubiquitous learning is very effective. Kong, J [17] proposed a network teaching mode of flipped classrooms and applied it to Exercise Physiology. Results showed that the network teaching mode of flipped classrooms increased students' learning interest and improved the teaching effect. Shih, S. C et al.[18] created a ubiquitous learning environment, which can improve students' mathematical performances, extra tutoring effect, and mathematical connection ability. Chen, C. M et al.[19] pointed out that developing a context-perceived mobile learning system can support learners to learn knowledge through mobile devices without temporal or spatial constraints. It realized a new context perceived ubiquitous learning mode. Aljawarneh, S. A [20] pointed out that ubiquitous learning could improve environmental perception and learning experiences, establish a relaxed interaction between real and digital learning resources, and provide personalized learning opportunities. Suartama, I et al.[21] pointed out significant differences between groups using ubiquitous learning strategies and electronic learning strategies in terms of learning initiatives and academic performances.

Based on the literature review, it concludes that DT technology can facilitate learners to participate in learning inquiry activities and support decision-making on solutions to problems. In the ubiquitous learning environment, teachers can design cooperative inquiry learning activities according to problems that learners encountered in the preview stage. During cooperative exploration, learners can control physical entities in the DT intelligent learning space to verify hypotheses and improve schemes. Learners can make transregional and high-simulation experience cognition of learning objects through situation awareness and realize continuous exploration of problems through a series of learning activities, such as research hypotheses, verification of reasoning, and improvement of schemes. This way, the continuous iteration of logic reasoning and abstract experiences is reached. This study proposed four core subsystems of DT ubiquitous learning by analyzing characteristics of learning activities with references to the components of learning spaces like intelligent and active learning spaces. These four core subsystems were the virtual-reality symbiotic system, information transmission system, intelligent control system, and teaching support system.

The influences of these four subsystems of DT technology on the ubiquitous learning effect were analyzed. Thus, the following hypotheses were proposed.

H1: The virtual-reality symbiotic system facilitates learners to improve the ubiquitous learning effect.

H2: The information transmission system facilitates learners to improve the ubiquitous learning effect.

H3: The intelligent control system facilitates learners to improve the ubiquitous learning effect.

H4: The teaching support system facilitates learners to improve the ubiquitous learning effect.

3. Methodology

3.1 Questionnaire design

Based on the above analysis, DT technology can support two-way data flow in the full life cycle between virtual twins, thus realizing the real-time correlation between the learning content of physical entity and DT learning content. In this study, a questionnaire to analyze the influences of DT technology on the ubiquitous learning effect was designed, which involves 25 questions on three aspects. The first aspect refers to the general information of respondents, including name, major, grade, and contact time of ubiquitous learning. The second aspect measures four subsystems of DT technology: virtual-reality symbiotic system, information transmission system, intelligent control system, and teaching support system. Specifically, 4, 5, 4, and 4 questions were designed for these four subsystems. The third aspect used the research questionnaire of Lee, H. S et al. [22], and four questions were chosen. All questions used a 5 point Likert scale.

3.2 Research objects

Seven universities in Zhengzhou City, Henan Province, China were chosen for the questionnaire survey. Key attentions were paid to engineering undergraduates. A total of 298 questionnaires were sent online (www.wjx.cn), among which 256 questionnaires were collected and 235 were considered valid. The collection rate of questionnaires was 78.86%. Statistical results are shown in Table 1.

Table 1. Descriptive statistical results of respondents

Name	Options	Frequency	Percentage (%)
Gender	Male	145	61.70
	Female	90	38.30
Grade	Freshman	30	12.77
	Sophomore	68	28.94
	Junior	85	36.17
	Senior	52	22.13
Major	Chemical engineering and technology	32	13.62
	Pharmaceutical engineering	53	22.55
	Applied chemistry	23	9.79
	Environmental engineering	32	13.62
	Material chemistry	41	17.45
	Water quality science and technology	54	22.98
Contact time	<1 year	17	7.23
	1–2 years	67	28.51
	2–3 years	87	37.02
	>3 years	64	27.23

4. Results analysis and discussion

4.1 Reliability and validity tests

Reliability analysis is used to study the answer reliability and accuracy of quantitative data (especially the questions on the attitude scale). First, Cronbach α was analyzed. If it is higher than 0.8, the reliability is high. If it is between 0.7 and 0.8, the reliability is relatively good.

Table 2 shows that the overall Cronbach α of the questionnaire is 0.850 (>0.8), indicating the high-reliability quality of data. Furthermore, the Cronbach α of different variables is higher than 0.7, indicating high overall reliability.

Table 2. Reliability analysis results

Variables	Number of question options	Cronbach α	Cronbach α
Virtual-reality symbiotic system (X1)	4	0.786	0.850
Information transmission system (X2)	5	0.887	
Intelligent control system (X3)	4	0.819	
Teaching support system (X4)	4	0.754	
Ubiquitous learning effect (Y)	4	0.905	

Table 3. KMO and Bartlett tests

KMO value		0.785
Bartlett sphericity test	Approximate Chi-square	2620.658
	df	210
	P value	0

Table 4. Distinguishing validity

	X1	X2	X3	X4	Y
X1	0.708	-	-	-	-
X2	0.313	0.786	-	-	-
X3	0.099	0.227	0.748	-	-
X4	0.163	0.223	0.16	0.684	-
Y	0.242	0.318	0.136	0.243	0.841

Notes: Blue numbers in clinodiagonal are AVE square roots.

Validity was verified by KMO and Bartlett tests. Table 3 shows that the KMO value is 0.785 (0.7–0.8), and the corresponding P value is 0.000 (<0.01), indicating that research data is applicable to extract information.

The AVE square roots of X1, X2, X3, X4, and Y are higher than the maximum absolute value of the correlation coefficient among factors, implying that these factors have good distinguishing validity.

4.2 Regression analysis

Table 5 shows that the model passed through F-test (F=10.276, p=0.000<0.05).

(1) H1 is true. The virtual-reality symbiotic system facilitates learners to improve the ubiquitous learning effect. Given high-efficiency data communication between physical equipment and DTs in ubiquitous learning, it realizes the state of virtual-reality connection and virtual-reality integration. Supported by virtual-reality symbiotic technologies, it can recognize high-efficiency interaction among several subjects (students, teachers, and equipment) and change the whole knowledge evolution process of ubiquitous learning. Thus, the several application scenes of ubiquitous learning are realized, and learners accept the ubiquitous learning more positively. In particular, more complicated nonlinear knowledge can present some field domain characteristics after the learning space is built based on DT technology. According to the closed self-organization of data closed ring, learners find it convenient to call nonlinear knowledge among ubiquitous learning knowledge nodes. Given that DT technology interacts with learners by using the model as the communication media, transforming into specific morphology adapting to the learning characteristics of learners is convenient for visual understanding of learners. Learning activities based on DT intelligent learning space surpass the traditional learning activities that center on learning content, cooperation, discussion, and symbol interaction. They also provide learners a ubiquitous learning environment and learning resources that can be observed, experienced, operated, verified, and developed.

(2) H2 is true. The information transmission system facilitates learners to improve the ubiquitous learning effect. The information transmission system can acquire the state data of ubiquitous learning effect using the Internet of Things (IOT) technology and complete the data transmission mission between virtual twins. In the ubiquitous learning scene of distributed multi-physical spaces, the information transmission systems can cooperate and integrate data of various learning physical spaces and make timely responses to state changes between learning virtual and real spaces. State and behavioral information of learners are acquired through technologies like IOT. Data is transmitted to the learning support system of the cloud service layer through high-speed communication technology.

Table 5. Regression results

Variables	Normalization coefficient	T value	P value	F
Constant	-	1.464	0.145	
X1	0.139	2.17	0.031*	
X2	0.228	3.45	0.001**	F (4,230) =10.276, p=0.000
X3	0.144	3.72	0.000**	
X4	0.162	2.57	0.011*	

D-W value: 1.308; * p<0.05 ** p<0.01.

The data information and operation command are transmitted to corresponding physical entities to drive them to change learning states and learning behaviors. Ubiquitous teaching activities are mainly practice explorations, during which ubiquitous learners make observation experiences, scheme tests, cooperative communication, reflection, and improvement. The key of information transmission is to acquire states of learners through the real-time state of virtual-reality twins and make the scientific and accurate prediction of possible states, thus enabling intelligent supports for various learning in the DT intelligent learning space. So fully considering learners' needs for personalized learning and explosive learning when building the ubiquitous learning space is necessary to realize effective support for teaching activities. For this purpose, the intelligence of learning space operation is realized. It helps teachers and learners in the real-time analysis of learning behaviors and learning performances and provides refers to design and perfect teaching activities.

(3) H3 is true. The intelligent control system facilitates learners to improve the ubiquitous learning effect. The core of cloud service is the intelligent control system responsible for collecting data from physical and digital spaces and sending commands. The intelligent control system can realize various functions, such as ubiquitous learning analysis, learning alarming, video and audio processing, and image processing. Furthermore, the intelligent control system can analyze and process relevant data according to ubiquitous learning behavioral state and operation commands of learners. The real-time intelligent information feedback can help learners to improve schemes timely. The intelligent control system can provide learners various services, such as learning monitoring of ubiquitous learning, intelligent classmates, and accurate teaching. It can provide technological support to ubiquitous independent study and large-scaled cooperative learning of learner groups. Data information of the full learning period of ubiquitous learners can be completely stored and used to analyze learning activities and predict learning behaviors, thus providing strong support for improving academic performances and optimizing teaching schemes. The intelligent control system transforms learning content and learning tasks into teaching

problems and situations that students are interested in by creating problems. On this basis, learning activities are organized through intelligent tutors, intelligent classmates, and big data analysis technology. Moreover, the intelligent control system realizes intelligent guidance and technological support for relevant knowledge learning.

(4) H4 is true. The teaching support system facilitates learners to improve the ubiquitous learning effect. The teaching support system is the fundamental representation of DT intelligent learning space teaching attributes. This system is mainly composed of DT classrooms, DT teachers and students, and learning behavioral evaluation systems. DT classroom provides a high-fidelity teaching and learning place for learners and teachers in ubiquitous learning and realizes cross-spatiotemporal cooperative learning mode. Learners and teachers can interact and communicate in the DT classroom through a personalized virtual form. The behavioral learning evaluation system can provide support to the real-time analysis of whole learning activities and academic performances of learners and the prediction of their behavioral learning trends. During ubiquitous learning in different places, DT ubiquitous learning space has to coordinate subsystems quickly and provide technological support to the learning activities of learners, such as practice operation, cooperative interaction, observation, and reflection. Therefore, the overall system design of different subsystems is realized through individual and intelligent functions. The teaching support system provides abundant data for learners to solve complicated problems, proposes suggestions for practice improvement, and facilitates the development of learners' deep learning and high-order thinking ability. It is conducive to improving the learning effect of learners comprehensively.

4.3 Discussions

DT technology is mainly advantageous for breaking restraints over teaching sites, and it can realize more personalized ubiquitous learning experiences. DT technology provides a fresh new learning space that supports to core competence and ability training of learners. Building a good ubiquitous learning space provides technological support to explore the potential of learners in improving deep learning and high-order ability. It is also conducive to enhancing the learning effect significantly. Based on intelligent guidance and learning support of DT intelligent learning space, learning content and learning task are transformed into questions or situations that students are interested in by creating questions. Learning activities are organized by intelligent tutors, intelligent classmates, and big data analysis technology. With the DT technology development, every learner in the future may have a corresponding DT to make real-time records, analyses, and predictions of our physical and psychological changes in the virtual world. DT, Internet of Everything, and any entity resource that can be perceived are all symbiotic resources combining twins. The dialogue with learners is built by interpreting the twin of learners, and the twin accompanying learning mode is established. A more accurate DT technology is constructed through a virtual-reality symbiotic system, information transmission system, intelligent control system, and teaching support system, which can improve the ubiquitous learning effect of learners comprehensively.

5. Conclusions

Technologies like network communication, VR, artificial intelligence, and 5G solve the asynchronous problem of teaching-learning behaviors between teachers and students caused by spatiotemporal separation. DT technology can build an intelligent learning space with high fidelity, real-time interaction, virtual-reality symbiosis, and expandability. It can support learners to explore nature and society independently, promote their high-order thinking development, and innovate the learner-centered intelligent management and learning mode. It can facilitate effective learning outcomes and realize the crossing and integration of the virtual and natural learning spaces. A questionnaire to discuss the influences of DT technology on the ubiquitous learning effect is designed based on the DT technology theory. The influences of four subsystems of DT technology (virtual-reality symbiotic system, information transmission system, intelligent control system, and teaching support system) on ubiquitous learning effect are analyzed. Results demonstrate that the overall Cronbach α of the designed questionnaire is 0.850 and KMO is 0.785, indicating that the questionnaire has good reliability and validity. All four DT technology subsystems have significantly positive influences on the ubiquitous learning effect. It is suggested to study further the influences of learners' interactive behaviors on learning performances deeply and continuously from components and the teaching facility strategies of DT intelligent learning and learning analysis technology.

Acknowledgements

The authors are grateful for the support provided by the Education and Teaching Reform Project of Henan Province (2020JGLX075, 2021SJGLX251Y, 2021XJGLX06).

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