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Research on the Construction of Technology-rich Classroom Learning Environment to Develop English Language Learning and Higher-order Thinking

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Abstract

Background and Aim: Applying emerging technologies to explore new learning ecology has become the focus of current education reform. Foreign language majors in China were once criticized for their lack of critical thinking abilities. This paper aims to construct a technology-rich classroom learning environment and explore its impact on participants' English learning and higher-order thinking.

Materials and Methods: This research is a quasi-experimental research design using a quantitative research approach. English language teaching experiment was conducted on 60 samples selected by using the purposive sampling method. Participants were university second-year business English majors, and their English listening, speaking and higher-order thinking skills were pre- and post-tested. Data were collected through tests and quantitative questionnaires. Descriptive statistics and paired-sample T-tests on the hypothesis were conducted by using the statistical software Jamovi.

Results: Participants showed a high evaluation of the constructed technology-rich classroom learning environment. Their English listening skills and speaking competency have been efficiently improved, especially listening comprehension, speaking content, and language use. Their higher-order thinking was also improved, especially their analytical ability and cognitive maturity. Meanwhile, participants demonstrated a high level of cognitive engagement and learning satisfaction.

Conclusion: This study proposed a model for technology-rich learning environment design, as well as a constructivist instructional design model, revealing the mechanism of technology promoting learning and providing relevant methods. The study also demonstrated that the simultaneous development of foreign language learning and higher-order thinking could be achieved in a technology-rich environment. This paper also puts forward suggestions for further enriching instructional design and technology-rich learning environment design.

Keywords: Technology-rich Learning Environment; English Learning; Higher-order Thinking

Introduction

The wide application of emerging technologies in the field of education, such as information and communications technology, virtual technology, cloud computing, and digital new media, has had profound impact on learning: learning content is getting richer and stronger; learning methods are getting more diversified; learning environment is getting smarter; learning modes are getting blended, and the interaction between people is getting faster and more convenient (Greg, 2018; Groff, 2013; Hare, Ault, & Niileksela, 2011). Applying emerging technologies to explore new learning ecology has become the focus of current language teaching reform (Wen, 2019). The rapid development of technology has also promoted the demand for high-level innovative talents. It has been a consensus that 21st-century education should prioritize students' skills for higher-order thinking (Hopson, Simms, & Knezek, 2001; Mainali, 2012; McMahon, 2007; Richland & Simms, 2015). Higher-order thinking ability has received unprecedented attention in various countries and has been incorporated into the national education framework (Collins, 2014).

With the development of modern technology, China's foreign language education has made

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tremendous progress in recent decades. However, it has often been commented by Chinese scholars for neglecting the development of students' higher-order thinking abilities and problem-solving skills (Zhong, 2005a). Huang (2010)criticized English majors with "Absence of Thinking", and strongly called for foreign language teaching reform. As Fisher (2008) pointed out English language teaching needs to shift from focusing on language accuracy and fluency to focusing on critical understanding and expression of language. Currently, the goal of foreign language teaching in China is not only to train learners with proficient language knowledge and skills but also to develop their high-order thinking and communication skills, which have been written in the national standards for teaching quality of undergraduate majors (National Administry Committee of Higher Education of Chinese Ministry of Education, 2020). Meanwhile, modern information technologies offer a variety of possibilities for the creation of new learning environments, and the restructuring of the learning environment supported by technology will be truly realized (Matielo & Farias, 2014; Rüschoff & Ritter, 2001; Salaberry, 2001; Stanley, 2013; Warschauer & Kern, 2000).

Based on the theory of Constructivism and the framework of Yang and Huang (2015) for designing a technology-rich classroom, this study constructed a technology-rich classroom and proposed instructional designs to promote the synchronous development of foreign language learning and higher-order thinking.

Objectives of the Research

This paper aimed to construct a technology-rich classroom learning environment and explore its impact on participants' English listening and speaking learning, as well as the development of higher-order thinking. It also attempted to understand participants' classroom engagement and learning satisfaction with learning in this environment, to provide some suggestions for the new modal of foreign language teaching.

Literature Review

Constructivism theory

Constructivism is considered a major theory of learning, and in a broader sense a philosophy of education, trying to understand how we construct knowledge. As a dominant learning theory, constructivism inevitably has a great influence on teaching and learning (Porcaro, 2011). Bodner (1986) pointed out that the core of the constructivist learning theory is that learning is not students' passive acceptance of the knowledge granted by the teacher, but the active construction based on their original knowledge and experience. Taber (2006) made further elaboration on the core ideas of constructivist learning theories and also pointed out the teaching proposition of constructivism that should focus on providing learners with rich and diverse learning situations related to the life and existing knowledge of the learner, where they can be actively involved. Learners are guided to grow new knowledge from their original knowledge and experience. The role of a teacher as a tutor is also emphasized.

There is a great amount of research on constructivist teaching and learning (Applefield, Huber, & Moallem, 2000; Duffy & Jonassen, 1991; Jonassen, 1999; Nanjappa & Grant, 2003). From the previous research, it could be summarized that constructivist teaching and learning explore and stimulate students' prior knowledge or pre-concepts, give students opportunities to participate in real and complex activities, as well as provide students with a large number of original materials and operating materials. Students are encouraged to cooperate, discuss, express their ideas, and use new concepts or knowledge in real

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situations. Reflection, independent thinking, and multiple evaluations are employed in the process. The process is viewed as more important than the result, where students are centered and encouraged to actively participate. The classroom learning environment is democratic, and teachers and students share power and responsibility. Learning activities must be flexible and adapt to the different needs of learners and the learning results are diverse, not necessary, and impossible to be the same.

Learning environment

As for the origin and development of the research on learning environment, it could be seen that it started from psychologists' attention to the research on the impact of the environment on human behavior, then to the research on the instructional environment with the emphasis on the physical aspects, and later to the research on the humanistic and student-centered learning environment with emphasis on the psychosocial aspects. This clue shows that the research focus of learning environment has shifted from people to the environment, and then back to people. Since the 1990s, scholars have made great efforts to understand and define the learning environment (Brush & Saye, 2000; Jonassen, 1994; Jonassen, 1999; Wilson, 1995; Zhong, 2005b). Fraser (1998a) stated learning environment encompassed social, physical, psychological, and pedagogical contexts in which learning occurs and affects student achievement and attitudes. Zhong (2006), presented that a learning environment was a learning space created to promote the development of learners, especially the development of high-level abilities, including physical space, activity space, and mental space.

It is found that although the definitions have differences in expression, they directly or indirectly show commonality: the environment is a learning space or a place; the environment provides sustainable power of support; the elements of the environment are mainly composed of technical resources, tools, and human beings; the environment mainly supports autonomous, exploratory, collaborative or problem-solving learning; learners control their learning. A learning environment is a combination of various support, such as teaching and learning resources, tools, teachers, a psychological environment, and other elements. Teaching and learning need to be designed. It is student-centered and influenced by constructivism.

Technology integration

The term technology integration has been frequently used by different people in different contexts to mean different things. Some scholars' understanding of technology integration is teachers' technology use such as the use of computers, the internet, videos, etc. in the classrooms (Bauer & Kenton, 2005; Bradley & Ross, 1993; Gülbahar, 2007). Some scholars were interested in the learning environment where technology was used to support teachers in carrying out activities more easily and productively (Harwell, Gunter, Montgomery, Shelton, & West, 2001; Najdabbasi & Pedaste, 2014). Other scholars defined it in the aspect of pedagogy advantages of technology used to improve students' performance and thinking skills (Adair-Hauck, Willingham-McLain, & Youngs, 2000; Hopson et al., 2001). It seems that there is not a clear standard definition of technology integration, but there are some prevailing elements in the current discussion. According to Ghavifekr and Rosdy (2015), technology integration occurs if: teachers are well-trained in the use of a full range of technology and the determination of their appropriate roles and applications; teachers and students can use technology on a routine basis when needed; teachers and students were supported when they chose to use some kind of technology.

In the field of foreign language teaching, it is supported scholars that language teaching method has been changed due to the integration of technology (Ahmad, 2012; Altun, 2015; Mohammad & Farhana, 2018; Rüschoff & Ritter, 2001; Stanley, 2013). The history of using technology to improve language learning is long and can be traced back to the times when phonographs and radios were used (Salaberry, 2001). Scholars from the past to the present have acknowledged the pedagogical advantages and effectiveness of technology used in

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language teaching and learning (Amin, 2019; Clarke, 1918; Kern, 1995).

Conceptual Framework and Research Hypothesis

Based on the review of the literature and the relevant theoretical framework, the conceptual framework of the research is developed as shown in Figure 1.

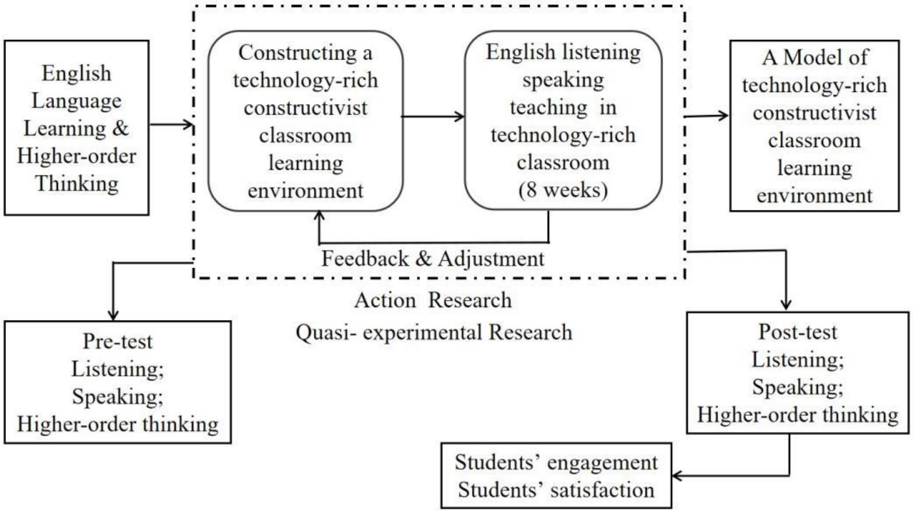

Figure 1 Conceptual Framework of the Research

English listening and speaking skills

Listening, speaking together with reading, and writing are the four skills in language learning. Listening is the cognitive process whereby we attach meanings to aural signals. It is the active intellectual of decoding, understanding, interpreting, and evaluating messages (Wah, 2019). Speaking ability refers to the ability to express oneself through oral language expressions. It is a comprehensive ability that not only involves speaking skills, such as pronunciation and intonation but also includes a person's thinking ability, knowledge, intelligence, etc. (Sosas, 2021). The logic, profundity, flexibility, and agility of thinking greatly affect the accuracy, organization, extensibility, and adaptability of speech. Higher-order thinking has always been involved in listening and speaking practice. Thus, this paper puts forward the following assumptions:

H_a1: The students' English listening score is improved after learning in the technology-rich classroom.

H_a2: The students' English-speaking score is improved after learning in the technology-rich classroom.

Higher-order thinking Ability

The term "higher-order thinking" has been used broadly and defined variously across disciplines and within content domains (Richland & Simms, 2015). Philosophers prefer critical thinking, reflective thinking, and logical reasoning (Cuban, 1984; Ennis, 1987; Lipman, 1991), while psychologists emphasize problem-solving, and metacognition (Flavell, 1979; Gagne, Wager, Golas, Keller, & Russell, 2005), and cognitive scientists focus on cognitive strategies (Bråten, 1993). Educators advocate the development of learning and problem-solving skills (Bradley & Ross, 1993; Ivie, 1998). Despite there are various definitions of higher-order thinking, the broadest attention to higher-order thinking has derived from Bloom's taxonomy of educational objectives (Richland & Simms, 2015), which describes the levels of cognitive achievement in line with the contemporary psychological principles (McMahon, 2007).

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Most researchers have agreed that higher-order thinking involves complicated cognitive activities, they also agreed that a popular strategy for fostering higher-order thinking is to design and implement instructional interventions that make learners involved in complex cognitive tasks or activities (Bagarukayo, Weide, Mbarika, & Kim, 2012). Kelman (1990) identifies higher-order thinking skills as one of the instructional areas that could be improved by using the computer. Salomon (1990) supported the idea that computers could be used as an effective classroom tool. Studies have shown that when learning occurs in a technology-rich learning environment, learners' higher-order thinking could be improved and the learning process could be qualitatively transformed (Bradley & Ross, 1993; Hopson et al., 2001). It is concluded that a technology-enriched classroom learning environment has a positive effect on students' acquisition of higher-order thinking skills. Researchers have thus vigorously sought to identify how to design and implement technology so that learning environments truly enhance learning and higher-order thinking learning (Miri, David, & Uri, 2007; Yusuf, Widyaningsih, Prasetyo, & Istiyono, 2021). Therefore, this paper puts forward the following assumptions:

H_a3: The students' higher-order thinking abilities are improved after learning in the technology-rich classroom.

Classroom engagement and learning satisfaction

Student engagement plays an essential role in learning and it represents a key component of student success (Vinson, Nixon, Walsh, Walker, Mitchell, & Zaitseva, 2010). There is no agreed definition of it since it is complex and multifaceted (Kahu, 2013). This paper adopted the most prevalent conceptualization from Fredricks, Filsecker, and Lawson (2016) that engagement consists of three aspects, behavioral engagement, affective engagement, and cognitive engagement. Behavioral engagement refers to observable behavior such as time-on-task, overt attention, classroom participation, question-asking, and choice of challenging tasks. Affective engagement refers to positive emotions during class, such as interest, enjoyment, and enthusiasm. Cognitive engagement refers to mental effort, such as meaningful processing, strategy use, concentration, and metacognition.

Student satisfaction is considered an important factor in evaluating the overall success of teaching and learning, as well as an essential indicator of the quality of learning experiences (Alamri, 2019). Student satisfaction can generally be defined as the extent to which students achieve the desired academic outcomes and experiences associated with education, and it also refers to the level at which students meet their academic goals and demonstrate the knowledge gained throughout the learning period (Uka, 2014). Researchers suggest investigating students' satisfaction in technology-enhanced learning settings because new technologies have altered the way of teaching and learning to a great extent (Kaminski, Switzer, & Gloeckner, 2009).

Methodology

The objective of this research was to explore the impact of the constructed technology-rich classroom learning environment on students' English language learning and higher-order thinking, so the quasi-experimental research design was applied, and a teaching experiment was conducted on 60 samples selected from Leshan Normal University in Southwest China. A quantitative research approach was used, and data were collected through tests and quantitative questionnaires.

Population and Sample Size: The target population of this research was university English majors in Southwest China. They have been studying English for at least 8 years (from primary school to university). They also have background knowledge of using technology as they have taken computer

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information technology courses from middle school to university. Everyone has a mobile phone and a computer, or an iPad. Their average age is around 19 years old, and they are a generation that has grown up with the rapid development of information technology. According to the sample size calculated by the software Gpower, at least 44 participants were needed in the study.

Sampling Method: The purposive sampling method was used to select samples (Acharya, Prakash, Saxena, & Nigam, 2013). Two classes taught by the researcher were selected, with 30 students in each class and a total of 60. The samples were second-year English majors from the Foreign Languages School of Leshan Normal University in Southwest China. They were around the age of 19 to 21. They had English listening and speaking classes once a week. They used to have this class in traditional classrooms with simple technology, but the teaching experiment they participated in was conducted in a newly built smart classroom. They know information technology, so they can use technology to assist their learning.

Research Instrument: The standardized national test for English majors was used to measure students' English listening and speaking skills. The total score of listening tests is 30 points, with 10 points for dictation and 20 points for listening comprehension. The total score of the speaking test is 100 points, graded from five aspects, namely language use, vocabulary, pronunciation, fluency, and content, with each aspect accounting for 20 points.

Students' higher-order thinking abilities were tested by using the test and a 6-level Likert scale questionnaire (Revised Critical Thinking Disposition Inventory), which were developed by a team led by Chinese scholar Wen Qiufang (Wen, Liu, Wang, Wang, & Zhao, 2010). The total score of the higher-order thinking test was 30 points, and the questionnaire to measure thinking tendency contained 50 question items which were categorized into eight dimensions, truth-seeking, open-mindedness, analyticity, systematicity, self-confidence, inquisitiveness, cognitive maturity, and justice-orientedness. The questionnaire used to measure students' classroom engagement consisted of 18 items from three aspects, behavioral engagement, affective engagement, and cognitive engagement (Fredricks et al., 2016). The questionnaire to measure learning satisfaction contained 30 items from the dimensions of instructor, course, technology, and environment (Stefanovic, Drapsin, Nikolic, Scepanovic, Radjo, & Drid, 2011). Moreover, the Classroom Environment Evaluation Scale questionnaire was used to understand students' evaluation of the technology-rich learning environment, with the aspects of showing, manageable, accessible, tracking, enhancement, teacher support, involvement, investigation, task orientation, and cooperation (Yang & Huang, 2015). The last three questionnaires were measured with a 5-level Likert scale ranging from disagree to agree.

Reliability and validity of the instruments

Content validity of the questionnaire items was conducted using the Index of Item Objective Congruence (IOC) by three experts, who hold a doctoral degree and have at least fifteen years of teaching experience in the field of English language teaching or education in the university. The IOC results showed that the lowest score for each scale item was 0.67, indicating all the variables achieved ideal content validity and the questionnaires were valid to use for data collection.

A pilot test was carried out to examine the internal consistency reliability of the research instruments. According to Hassan, Schattner, and Mazza (2006), 30 respondents would be adequate for the pilot test. Therefore, 35 English majors who had a learning experience in technology-rich classrooms participated, and the internal consistency reliability was analyzed by using Cronbach's Alpha indicator. Pilot test results showed that all the Cronbach's Alpha values were higher than 0.75,

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indicating that the internal consistency reliability of each questionnaire was satisfactory (see Table 1).

Table 1 Reliability test result of the questionnaire

Variables	Number of Items	Cronbach's Alpha
Wen's Critical Thinking Disposition Inventory	50	0.871
Classroom Engagement	18	0.927
Learning Satisfaction	30	0.946
Classroom Environment Evaluation Scale	50	0.832

Data Collection and Analysis: The research began with pre-tests on students' listening and speaking skills and higher-order thinking abilities. Quantitative questionnaires were used to test participants' higher-order thinking tendencies. Then, eight designed English listening and speaking lessons were conducted in the constructed technology-rich classroom. At the end of the experiment, post-tests were run on students. Questionnaires were also used to understand students' evaluation of the classroom environment, classroom engagement, and learning satisfaction. The statistical analysis software (Jamovi) was used to analyze the data. Frequency and percentages were utilized to describe the sample's demographic information. Descriptive statistics, such as the mean, standard deviation, maximum, minimum, etc. were employed to understand the quantitative data and inferential statistics, paired-samples T-test, was applied for hypothesis testing to evaluate whether there is a significant difference in the mean of paired samples in the pre and post-tests.

Action Research: The characteristics of constructivist instructional design are reflected in seven aspects: the learning process, teaching and learning objectives, learning tasks, the role of teachers, the role of information technology, the role of learners, and learning evaluation. In the English teaching experiment, instructional design should reflect and practice the constructivist learning perspective. By referring to Yu's model of classroom teaching design, this paper proposed a model of constructivist instructional design, as Figure 2 shows (Yu, 2000).

In this instruction design, the first step is to analyze teaching objectives based on the teaching tasks. This would determine the theme of students' learning. The analysis of teaching objectives should be learner-centered and consider the characteristics of learners. Teaching objectives are not imposed by designers or educators on the learning process but are extracted from the learner's learning process. Next, learning content should be designed, including the problems to be solved, the cases to be studied, the projects to be conducted, etc. Combined with Jonathan's constructivist learning environment design ideas, it is believed that problems are the source of learning objectives, and the process of solving problems is the process of learning. Based on the learning content, learning resources, learning situations, cognitive tools, and learning strategies should be designed. Then, the role of the teacher, the support that can be provided, and the methods that can reinforce learning should be considered in the process of learning. Assessment of learning outcomes runs through the entire process, while constant reflection and feedback are needed to improve the instructional design.

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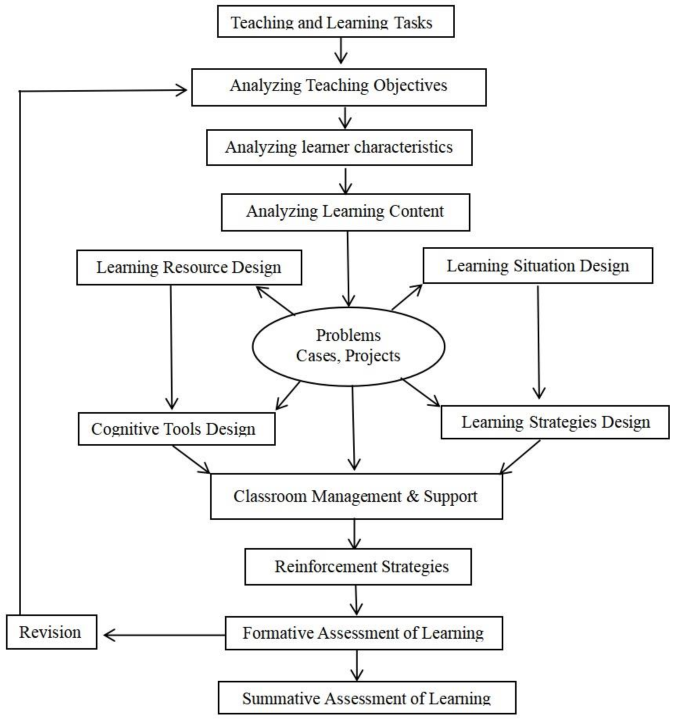

Figure 2 A model of constructivist instructional design

In this model, learning tasks, such as problems, cases, projects, etc. are the core, which originates from the analysis of the learning content. In the technology-rich classroom learning environment, information technology becomes a driving force for the learning content. Thus, learning content should be related to information technology. Then, a “technology-driven design” approach should be used to design learning content. It refers to the design of various elements of the learning environment around the characteristics of information technology tools, while fully considering the support of information technology tools for achieving learning goals, and gradually improving the design during the process of using tools for learning. Using this approach to construct a technology-rich learning environment is not technology-centered. It is a kind of manifestation of learning with a technology orientation, which is based on the support of information technology tools for achieving learning goals. Therefore, the most crucial aspect of using this method for design is to deeply explore the functions of information technology tools, understand the learning objectives, and connect the two appropriately and creatively. Based on the above analysis, a constructivist learning environment could be constructed. Due to the characteristic of technology-driven design, then a model for technology-rich learning environment design was developed (see Figure 3).

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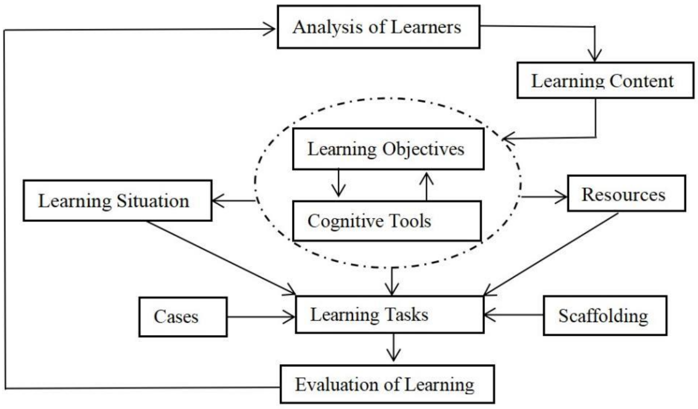

Figure 3 A model for technology-rich learning environment design

Results

Demographic information was used to describe the sample's profile. The findings of the quantitative analysis were derived using descriptive statistics and paired-samples T-test which was applied on hypothesis testing. Before the paired-samples T-test, the normality tests were done on the data collected from the tests, and the results showed that the p values were all higher than 0.05, indicating that the data conform to normal distribution. The three questionnaires of student classroom engagement, learning satisfaction, and classroom environment evaluation all used the 5-level Likert scale to collect data from respondents. An arbitrary level was utilized to interpret the data (see Table 2).

Table 2 Arbitrary level for the interpretation of data from the questionnaire of classroom engagement, learning satisfaction, and classroom environment evaluation (Pimentel, 2010)

Scale	Interpretation (for questionnaires on classroom environment evaluation and learning satisfaction)	Interpretation (for questionnaire of classroom engagement)
1-1.79	Disagree	Never
1.80-2.59	Partly Disagree	Seldom
2.60-3.39	Neutral	Sometimes
3.40-4.19	Partly Agree	Often
4.20-5.00	Agree	Almost always

Demographic Information

60 second-year English majors from two classes participated in the study. 53 of them were female, accounting for 86.7% of the total number of participants, and 7 were male participants (13.3%) (see Table 3). All the participants completed the pre- and post-English language tests and higher-order thinking tests, as well as the questionnaires. Participants' ages ranged from 19 to 21 years old. They came from the same grade and had similar age differences. Most participants were around the age of 19, accounting for 80% of the total, while those aged 19 and 20 account for 10% and 15%, respectively.

Table 3 Demographic information of the participants (n=60)

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Student demographic information		Quantity	Proportion
Gender			
	Male	7	11.67%
	Female	53	88.33%
Age			
	19 years of age	15	25%
	20 years of age	5	66.67%
	21 years of age	40	8.33%

Table 4 shows the number of years participants have used computers, mobile phones, and iPads. It could be seen that all the participants have had the experience of using computers, mobile phones, and iPads for years. They have been using computers and mobile phones for longer years than they have been using iPads. The vast majority of the participants (90%) have been using computers and mobile phones for 3 to 10 years, while they (85%) have been using iPads for about 1 to 5 years. Some of them have even longer years of computer and mobile phone use.

Table 4 Participants' personal use of computers, mobile phones, and iPads

Duration of Time	Computer	Mobile Phone	iPad
< 1 years	0 (0%)	0 (0%)	0 (0%)
1-3 years	4 (6.67%)	8 (13.33%)	20 (33.33%)
3-5 years	29 (48.33%)	28 (46.67%)	31 (51.67%)
5-10 years	25 (41.67%)	21 (35%)	8 (13.33%)
>10 years	2 (3.33%)	3 (5%)	1 (1.67%)

Descriptive Statistics for English listening and speaking performance

Data were first analyzed by using descriptive statistics to evaluate participants' English listening and speaking performance. Descriptive statistics in Table 5 showed that the average total score of the listening post-test was 1.92 points higher than that of the pre-test, with a growth rate of 6.33%. In terms of the score range, the difference between the highest and lowest scores in the listening test has changed from 11 points to 10 points. As for the two parts of the listening test, the average score change in dictation was very small, only 0.28 points, while the change in the listening comprehension score was 1.63 points. That means the change in the total score of the listening test mainly came from the change in the score of listening comprehension.

Speaking tests also showed an overall improvement as the average total score of the post-speaking test increased by 3.68 points, with a growth rate of 3.7%. The result of the various aspects of the speaking test showed that the mean scores for language use and content increased dramatically by 1.27 points and 1.49 points. However, the average scores for the other aspects, vocabulary, pronunciation, and fluency, only increased by 0.25, 0.11, and 0.51 points, respectively. This indicated that the improvement in total speaking scores was mainly caused by the improvement in scores in terms of content and language use.

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Table 5 Descriptive statistic results for listening and speaking tests (n=60)

	Pre (1)/Post (2)	Mean	SD	Minimum	Maximum
Listening	1	20.82	2.54	16.00	27.00
	2	22.79	2.49	18.00	28.00
-- Dictation	1	7.21	0.980	5.00	9.00
	2	7.49	0.876	6.00	9.00
-- Comprehension	1	13.62	1.688	10	18
	2	15.25	1.762	12	19
Speaking	1	79.10	3.526	70	85
	2	82.78	3.059	76	88
-- Language Use	1	15.03	0.863	13	17
	2	16.30	0.809	15	18
-- Vocabulary	1	16.88	0.846	15	18
	2	17.13	0.769	15	18
-- Pronunciation	1	16.47	0.892	14	18
	2	16.58	0.720	15	18
-- Fluency	1	15.97	0.663	15	17
	2	16.48	0.725	15	18
-- Content	1	14.73	0.733	13	16
	2	16.22	0.761	15	18

Descriptive Statistics for Higher-order Thinking Ability

To gain a clear understanding of participants' higher-order thinking abilities, both tests on higher-order thinking skills and a questionnaire survey on higher-order thinking tendencies were conducted on participants. Table 6 clearly showed that post-test scores on participants' higher-order thinking increased from 17.4 to 19.4, indicating an overall improvement in higher-order thinking ability. As for the questionnaire to measure thinking tendency, the score for each dimension ranges from 10 to 60 points. The calculation method is to add the scores of each question within each dimension, divide by the number of questions, and then multiply by ten. A score of 40 or above indicates a positive critical thinking tendency, a score of 30 or below indicates a negative thinking tendency and a score of 31-39 indicates a fluctuating tendency. Correspondingly, a total score of 320 or above indicates a positive tendency, a score of 240 or below indicates a negative tendency, and a score of 241-319 indicates a fluctuating tendency (Wengensteen, 2010). The results of the questionnaire demonstrated that before the experiment, the average score of the whole questionnaire was 313.7 points, indicating an approaching positive tendency. The fluctuating tendency could be seen in five dimensions: truth-seeking, open-mindedness, systematicity, self-confidence, and cognitive maturity because the scores range from 31 to 39. After the experiment, the average score increased by 30 points to 344.1, exhibiting a very positive critical thinking tendency. All the dimensions

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except the dimension of truth-seeking (38.2) presented a very positive critical thinking tendency, as the score of each dimension exceeded 40 points.

Table 6 Descriptive statistic results for participants' higher-order thinking (n=60)

	Pre (1)/Post (2)	Mean	SD	Minimum	Maximum
Higher-order Thinking skills test	1	17.4	2.09	13	22
	2	19.4	2.07	15	24
Higher-order Thinking Disposition	1	313.7	15.02	285.0	351.0
	2	344.1	19.41	312.8	388.4
--Truth-seeking	1	33.2	3.87	25.7	42.9
	2	38.2	2.85	32.9	45.7
--Open-mindedness	1	38.3	3.67	31.7	50.0
	2	41.7	3.20	35.0	50.0
--Analyticity	1	41.8	2.61	32	48
	2	47.0	5.48	36	58
--Systematicity	1	36.4	3.96	26	44
	2	40.5	4.60	28	48
--Self-confidence	1	36.9	4.79	27.1	48.6
	2	40.6	4.96	27.1	50.0
--Inquisitiveness	1	42.8	5.68	26.7	55.0
	2	46.1	6.44	28.3	60.0
--Cognitive Maturity	1	36.5	3.53	27.5	42.5
	2	41.3	3.98	32.5	52.5
--Justice-orientedness	1	47.8	4.55	36.7	56.7
	2	48.8	3.30	41.7	56.7

From Table 6, there has been improvement in every aspect of higher-order thinking ability, but the most significant improvement can be seen in the dimension of analyticity, with an increase in the average score of 5.2 points, followed by the dimensions of truth-seeking and cognitive maturity, with a growth of 5 points and 4.8 points. The average score of other aspects has all improved to a certain degree.

Descriptive Statistics for Classroom Environment Evaluation

The 5-level Likert Scale questionnaire Classroom Environment Evaluation Scale consists of 10 dimensions which are divided into two categories: physical classroom environment and psychosocial classroom environment. Table 7 presents the item means and standard deviations for each dimension. The first five dimensions belong to the physical classroom environment, while the last five belong to

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the psychosocial classroom environment.

Table 7 Descriptive statistic results for Classroom Environment Evaluation Scale (CEES) (n=60)

	Mean	**SD**
Classroom Environment Evaluation Scale	**4.50**	**0.132**
--Showing	4.60	0.346
--Manageable	4.77	0.352
--Accessing	4.87	0.164
--Tracking	4.78	0.214
--Enhancement	4.49	0.256
--Teacher Support	4.62	0.239
--Involvement	4.71	0.157
--Investigation	3.77	0.261
--Task Orientation	4.44	0.271
--Cooperation	4.39	0.208

From Table 7, it can be seen that students' evaluation of the classroom environment received a score of 4.5. According to (Yang & Huang, 2015), it is assumed that the average score of 0–2 stands for bad classroom status, 2–4 stands for normal status, and 4–5 stands for the ideal status. This indicates that students have a good perception of the constructed technology-rich English language learning environment. Looking at the various aspects of the classroom learning environment, the scores were all between 4.3 and 4.9 points, except for one dimension (investigation) where the score was 3.77. This kind of classroom environment was characterized by relatively high levels of accessing, tracking, and managing, which conformed to the characteristics of a technology-rich learning environment. Participants rated the amount of investigation in these settings as relatively low, which indicated it was not convenient to investigate in the classroom. Overall, participants demonstrated a high level of evaluation for the both physical and psychosocial environment, but they rated the physical environment higher than the psychological environment.

Descriptive Statistics for Classroom Engagement

From Table 8, it could be seen that participants demonstrated a high level of engagement when learning occurred in a technology-rich classroom. Interestingly, it was found that cognitive engagement scored the most, up to 4.41 points, which suggested participants were cognitively involved in the technology-rich classroom learning.

Table 8 Descriptives Statistic Results for Participant Classroom Engagement

	N	**Mean**	**SE**	**Median**	**SD**
Engagement (Total)	**60**	**4.31**	**0.0434**	**4.39**	**0.336**
---Behavioral Engagement	**60**	**4.20**	**0.0563**	**4.20**	**0.436**
---Affective Engagement	**60**	**4.28**	**0.0536**	**4.40**	**0.415**

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Table 8 Descriptives Statistic Results for Participant Classroom Engagement

	N	Mean	SE	Median	SD
---Cognitive Engagement	**60**	**4.41**	**0.0459**	**4.50**	**0.356**

Descriptive Statistics for Learning Satisfaction

From the following Table 9, it can be seen that students' learning satisfaction received a score of 4.65, which means they were satisfied with learning in the technology-rich classroom. Looking at the various dimensions of learning satisfaction, the scores were all above 4.5 points, especially in the dimension of instructor's response and attitude toward technology and classroom technology quality, receiving high scores of 4.73 and 4.72 points, which means students were particularly satisfied with teacher's instruction and classroom technology. All in all, students demonstrated a very high level of satisfaction.

Table 9 Descriptives Statistic Results for Participant Learning Satisfaction

	N	Mean	SE	Median	SD
Satisfaction (Total)	60	4.65	0.0228	4.63	0.177
---Instructor's response and attitude toward technology	60	4.73	0.0345	4.80	0.267
---Course flexibility and quality	60	4.60	0.0351	4.65	0.272
---Classroom technology quality	60	4.72	0.0320	4.78	0.248
---Classroom interaction and learning assessment	60	4.54	0.0367	4.58	0.284

Hypothesis Testing Result

For hypothesis testing, a paired-sample t-test was conducted to evaluate whether the scores of the pre-test and post-test were significantly different. Table 10 presents the summary of the hypothesis testing results.

Hypothesis 1

Table 10 The summary of paired-sample t-test results for the hypotheses

			statistic	df	p	Mean difference	SE difference		Effect Size
L1	L2	Student's t	-17.9	59	< .001	-1.97	0.110	Cohen's d	-2.31
S1	S2	Student's t	-24.4	59	< .001	-3.68	0.151	Cohen's d	-3.14
HOT1	HOT2	Student's t	-16.6	59	< .001	-1.967	0.119	Cohen's d	-2.14
HOTD1	HOTD2	Student's t	-27.7	59	< .001	-30.42	1.10	Cohen's d	-3.57

H_a1: The students' English listening score is improved after learning in the technology-rich classroom.

For hypothesis 1, paired-sample t-test results in Table 10 showed that the mean of the post-listening test (L2) score (M=22.79, S.D.=2.49) was statistically better than the mean of the pre-test (L1) listening score (M=20.82, S.D.=2.54), as t (59) =-17.9, p<0.001. This indicated that the difference between the pre and post-test scores was significant. Learning in the technology-rich classroom was effective in

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terms of improving participants' listening ability. Thus, the first alternative hypothesis was supported.

Hypothesis 2

H_a2: The students' English-speaking score is improved after learning in the technology-rich classroom.

The statistical result in Table 10 validated the hypothesis that speaking competency was significantly improved after learning in the technology-rich classroom, as the mean of the post-test speaking (S2) score (M=82.8, S.D.=3.059) was statistically significantly better than the mean of the pre-test speaking (S1) score (M=79.1, S.D.=3.526), t (59) =-24.4, p<0.001. The second alternative hypothesis was therefore supported.

Hypothesis 3

H_a3: The students' higher-order thinking abilities are improved after learning in the technology-rich classroom.

For hypothesis 3, the paired-sample t-test result demonstrated that the mean of the post-test (M=19.4, S.D.=2.068) on participants' higher-order thinking (HOT2) was statistically better than that of the pre-test (HOT1) score (M=17.4, S.D.=2.07), as t (59) =-16.6, p<0.001. What's more, the mean of the post-higher-order thinking tendency (HOTT2) survey (M=4.30, S.D.=0.277) was also significantly better than that of the pre-survey (HOTT1) score (M=3.92, S.D.=0.176), as t (59) =-21.4, p<0.001. It indicated that learning in a technology-rich classroom has positive results on participants' higher-order thinking improvement. As such, the third alternative hypothesis was supported.

Discussion

Firstly, after learning in the constructed technology-rich classroom, participants' higher-order thinking abilities have been greatly improved, especially in terms of analytical ability and cognitive maturity. Meanwhile, their English listening skills and speaking competency have been efficiently improved, especially in terms of listening comprehension, language use, and speaking content. Because English listening and speaking involve a large amount of higher-order thinking activities, the improvement of listening and speaking cannot be separated from the contribution of the improvement of higher-order thinking. This indicates that the improvement of higher-order thinking can promote the improvement of English listening and speaking to some extent. The teaching design of the English class in this study fully considered the development of higher-order thinking, which was reflected in the listening and speaking activities. Moreover, information technology provided a wide range of resources, created learning contexts, and served as teaching tools, learning tools, and mindtools, which promoted higher-order thinking.

Secondly, participants were highly involved in the technology-rich classroom, particularly, their cognitive engagement has been greatly improved. In the constructivist technology-rich classroom, students actively participate in the construction of knowledge themselves under the guidance of teachers, thus great engagement would be put in the process of learning. What's more, the design of learning tasks specifically considered the improvement of higher-order thinking. As students' higher-order thinking improved, there would inevitably be a large amount of cognitive engagement involved.

Thirdly, participants were satisfied with learning in the technology-rich learning environment, especially with the teacher's instruction and classroom technology. This is consistent with their evaluation of their learning environment. Modern information technologies have altered the way of teaching and learning to a great extent. This generation of learners grows with the development of technology, and they are very fond of classroom teaching and learning supported by technology, which

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is very in line with their characteristics as digital learners. In addition, the teacher's instructional method, friendly teaching style, timely assistance and response, positive attitude towards the use of technology, convenient access to technology, handy software and learning tools, and so on, all allow students to demonstrate high levels of satisfaction and participation.

Fourthly, participants showed a high evaluation of the constructed technology-rich classroom learning environment, but they rated the physical environment higher than their psychological environment. This indicates that the change in the classroom environment is a gradual process from the physical environment to the psychosocial environment. The most obvious feeling for learners in a learning environment is the change in the physical environment, while the change in the psychological environment is a long-term process. At the same time, it is also influenced by the learners themselves, and the evaluation of the psychological environment will be influenced by more factors.

Conclusion

This study applied information technology in English language teaching and learning through the construction of a technology-rich classroom learning environment, to promote the development of learners' language competency and higher-order thinking. A quantitative research method was used to obtain evidence and test the effectiveness of information technology in promoting language learning and higher-order thinking. The study proposed a model for technology-rich learning environment design, as well as a model for constructivist instructional design, which revealed the mechanism of technology promoting learning and provided relevant methods

The mechanism of technology promoting learning

Firstly, information technology has provided a wide range of resources, created learning contexts, and served as teaching tools, learning tools, and mindtools. It has been demonstrated as an environmental force that supported the occurrence of language learning and higher-order thinking.

Secondly, technology has driven changes in the learning environment. The development of technology has promoted changes in the physical learning environment, such as teaching facilities, teaching tools, etc. At the same time, it also promoted changes in the psychosocial learning environment, such as technology integration in classrooms that encouraged learners to engage in proactive, cooperative, constructive, and exploratory learning.

Thirdly, technology is a specific method of transforming the learning environment to achieve specific teaching and learning goals. In the process of using technology for learning, learners' way of thinking will gradually change and have a certain relationship with technology.

The Way of Technology Promoting Learning

Technology and the learning environment are interdependent and work together to influence the development of learners learning and higher-order thinking. Constructing a technology-rich classroom learning environment is an effective way to leverage the interdependence between technology and the learning environment. Therefore, the way technology promotes learning could be summarized from three aspects.

Firstly, the design of the technology-rich learning environment, including the objective, model, and core idea. Second, the learning theory that supports the development of higher-order thinking should be based on constructivist theory, which also determined that the design of a technology-rich learning environment was based on constructivism and reflected the characteristics of the constructivist learning environment. Third, it is the core idea of technology-driven design. In the constructivist learning environment, there is a greater emphasis on the selection and use of technology as a cognitive

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tool. The technology-driven design approach is used in the design of learning content. It refers to the design of various elements of the learning environment around the characteristics of information technology tools, while fully considering the support of information technology tools for achieving learning goals, and gradually improving the design during the process of using tools for learning.

Recommendations

Constructing a technology-rich learning environment has become a trend in the field of education. Universities, teachers, and students are all participants in the construction of a classroom learning environment. For a technology-rich classroom to have a positive impact on learning outcomes, in addition to the technology itself, it is necessary to pay more attention to the instructional design and implementation of classroom learning, which is the core of a technology-rich classroom learning environment. Future research on technology-rich classroom environments should shift more toward classroom psychosocial environments.

In the experiment, it was found that one of the difficulties in constructing a technology-rich classroom was the IT application skills of teachers, which also affected instructional design and implementation, as well as students' classroom involvement and learning satisfaction. Therefore, it is urgent to improve teachers' technical skills, which requires universities and teachers themselves to make more efforts to keep up with the development of modern technology, but it undoubtedly poses a huge challenge to teachers. Future research could provide solutions to this problem.

Last but not least, with the development of technology, the concept of technology-rich will continue to be enriched, and future research cannot be limited to the current rich technology. More research should be provided to enrich the concept of technology-rich and to explore the richness of technology-rich learning environments.

Research deficiencies and prospects

The model proposed in this research has only been empirically studied on a small scale. The sample size is limited, and more empirical research is needed to prove and further improve it.

There is no exact definition for the concept of technology-rich. Different students in different universities in different countries have different evaluations of a technology-rich classroom environment. The evaluation results can only reflect the opinions of the experiment participants.

The instruction design and implementation emphasized in this paper require teachers with professional knowledge of educational technology, which may not be achievable by every teacher, so its popularization has certain difficulties, and more solutions are required.

The results of this study have a certain significance for English language teaching, but whether it can be generalizable for the teaching of other majors still needs more empirical research.

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