

A technology-enhanced scaffolding instructional design for fully online courses

Juan Yang, Rui Jiang, Han Su
Sichuan Normal University

The COVID-19 pandemic has forced teachers to implement fully online teaching. This study reviewed the popular technologies that are used in online learning, as well as the advantages and difficulties of applying fully online courses for formal education. Based on this research background, this study proposed a nested scaffolding design of an online course for 215 college students in China with the help of six technological tools, which effectively replaced face-to-face interactions and significantly improved the usage of the supporting learning platform. The inner-outer learning cycles supported by the technological tools improved the quality of the scaffolding conversations, reduced the scaffolding time cost that teachers had to expend and enhanced the effectiveness of the individualised scaffolding instructions.

Implications for practice or policy:

- First-year students' learning outcomes can be improved by the scaffolding support from Web 2.0 resource URLs, a small private online course, and EducCoder resources.
- Course leaders should construct at least 3–5 stage-wise evaluations to deconstruct the big learning process into several observable learning cycles, making the Kolb (1984) cycles controllable.
- Assessors may need to consider involving various exercises, such as quizzes, online experiments and synthesised tasks to facilitate students' learning.

Keywords: scaffolding, fully online course, technology-enhanced learning environment, college students, Web 2.0 tools

Introduction

Although web-based courses have been widely used to help learners engage in various learning processes, fully online teaching remains a big challenge. To date, the COVID-19 pandemic has forced many universities worldwide to replace face-to-face and blended classes with fully online classes (Moorhouse, 2020). Based on this background, Chinese universities have had to offer fully online courses to numerous college students (Ministry of Education, 2020). Over the past 10 years, reviews of meta-analyses have shown a moderate positive effect of emerging technological tools (Clark et al., 2016; Merchant et al., 2014; Tamim et al., 2011). However, how to improve technology-enhanced online courses' flexibility, security, efficiency, convenience and usability requires better solutions (Aljawarneh, 2020).

As indicated by Englund et al. (2017, p. 73), “the teachers' conception of and approaches to technology are central for implementing educational technologies in higher education”. Also, sound instructional design plays a critical role in technology-supported pedagogy (Bond et al., 2020). Moreover, in addition to the problems that have already been faced by online learning, guaranteeing learning engagement and interactions in large online classes is more challenging than ever before (Aljawarneh, 2020; Moorhouse, 2020).

Literature review

Web-based courses and blended learning

Despite the various learning objectives that learners pursue, online tutoring systems can be divided into formal and informal (Becker et al., 2017). Formal tutoring platforms are required to provide functions for defining learning objectives of the courses, learning resources (e.g., lectures, contents, topics, exercises, quizzes) for learners and management functions for teachers. Blackboard, WebCT and Moodle are typical online tutoring platforms for formal learning. Due to the full-function advantage, formal tutoring platforms

are intact; intactness implies that those systems lack sufficient flexibility to support varied instructional designs, as they are usually incompatible with other tools (Aljawarneh, 2020).

In contrast to Blackboard and Moodle, the massive open online course (MOOC) is a typical learning resource originally designed for informal learning. However, along with the discovery of the diverse usage of MOOCs, the integration of informal MOOCs into a formal teaching pedagogy has become a popular trend. The popularity of this blended learning format is because the design of MOOCs is based on established higher education programmes, which can offer quality courses for typical students (Legon, 2013). University MOOCs of China is one of the most popular MOOC platforms in China and is used by many university teachers in their blended classes (Zheng et al., 2018). However, there is increasing scepticism about the effectiveness of using MOOCs to implement formal learning objectives (Liyanagunawardena et al., 2013). Margaryan et al. (2015) sampled 76 MOOCs to evaluate their instructional design quality using 10 underpinning principles (Collis & Margaryan, 2005). Margaryan et al. found that the average instructional design quality of MOOCs is low. For example, only 9.2% of MOOCs had learning activities that attempted to activate prior knowledge or skills; only 6.5% of them encouraged learners to implement their knowledge integration; and only 6% of xMOOCs provided activity options for learners. An xMOOC is hyper-centralised and has linear organisation; learning resources are always in short, modularised video lecture format (Margaryan et al., 2015). Thus, in a postscript about the evolution of MOOCs, Baggaley (2014) suggested the use of small private online courses (SPOCs) to replace MOOCs.

A SPOC is a localised instance of xMOOC, which is deployed on a commercial platform and has a well-structured content organisation with video lectures as its primary learning material format (Baggaley, 2014). In contrast to MOOCs, SPOCs focus more on groups of students with the same learning objectives and with similar cognition backgrounds; thus, it is much easier for SPOCs to integrate instructional design, especially when the courses are used in a blended learning approach (Margaryan et al., 2015).

Ghadiri et al. (2013) advocated for promoting blended classes that combine online content with face-to-face pedagogical activities. However, with the rapid development of the Internet and emerging information technologies, informal tutoring platforms such as Web 2.0 tools are more easily accepted by students because of their openness and inexpensiveness. Cox (2013) revealed that the number of informal learning resources and learning materials accessed and used by students is far higher than that provided by schools over the past 40 years. He even argued that learning based on informal learning resources had an equal value to formal learning. However, studies have revealed that without sound pedagogy, technology promotes disengagement and impedes learning (Howard et al., 2016; Popenici, 2013), suggesting the high risks of conducting online teaching relying solely on technological tools.

Moreover, COVID-19 pandemic magnified the drawbacks of conducting fully online teaching grounded on digital tools (Moorhouse, 2020). Problems such as how to generate interest and motivate learners' interactions, how to effectively distribute and organise information, and how to schedule reasonable work hours for consultation, unsurprisingly have become a harsh reality confronted by teachers when they have to manage a large-scale online class (Aljawarneh, 2020; Blankley et al., 2019). To date, there is still no mature solution.

Although there is increasing scepticism about the effectiveness of exclusively using technological tools to distantly implement formal learning objectives, the COVID-19 pandemic has pushed these tools to the frontline (Moorhouse, 2020). With sound instructional design, digital tools can play a constructive role in overcoming the difficulties (Howard et al., 2016; Popenici, 2013).

Scaffolding designs in formal learning

Scaffolding was originally proposed to describe how parents and teachers provide heuristic assistance for children as they learn a skill in a task; for example, parents or teachers helping children construct a pyramid with wooden blocks (Wood et al., 1976). The use of scaffolding theory in education has a long history (see Belland, 2014, for review), especially in courses involving procedural knowledge, such as science, technology, engineering and mathematics courses (STEM courses; Belland, 2017). The scaffolding strategy has achieved prominent success in formal teaching across multiple disciplines during the past decades, especially in teaching K-12 courses (see Belland, 2014, for review).

Belland (2014, 2017) identified three distinctive scaffolding characteristics: dynamic assessment; providing the right amount of support; and intersubjectivity. However, Belland (2014, 2017) posited that the core spirit of scaffolding is that the assistance provided to students must be slightly ahead of what the students know. This core characteristic makes it possible to compensate for the disadvantages of web-based courses; for example, it can keep learners keen on a task (Belland, 2014). Therefore, the number and the way (static vs. dynamic) of the scaffolding support given to students are of vital importance in evaluating the performance of scaffolding. Not surprisingly, one-to-one scaffolding is acknowledged as the most effective mode (Belland, 2017). However, technology-enhanced scaffolding is expected to become the most efficient mode (Deep et al., 2020; Janson et al., 2020; Shin et al., 2020).

Researchers have identified examples and strategies to promote meaningful technology-enhanced scaffolding. Technology-enhanced scaffolding such as Geneticus Investigatio (Deep et al., 2020) can provide inquiry-driven reflective learning experiences for students. However, direct approaches to embedded in technology-enhanced scaffolds, such as telling students which problems to solve or how to solve problems, may undermine rather than cultivate problem identification (Kim & Hannafin, 2011). Learners may simply comply with directions rather than internalise guidance. Therefore, teachers tend to use technology scaffolds to supplement ongoing teaching approaches rather than relying solely on contextualised scaffolds to facilitate student problem-solving, that is, integrating technological scaffolds into their instructional design (Kim & Hannafin, 2011). Compared to technology-enhanced scaffolding, technology-enhanced scaffolding is semi-automatic, and the scaffolding environment is manually built by combining the functions of different technological tools according to instructional design.

With the development of artificial intelligence, digital scaffolding based on natural language processing (NLP) is expected to be a new form of automatic scaffolding, which can provide dynamic scaffolds to students instead of embedded scaffolding strategies (Albacete et al., 2019; Winkler et al., 2020; Winkler et al., 2021). Unfortunately, until the COVID-19 pandemic, digital scaffolding based on NLP was still in the experimental stage. The product of NLP-based scaffolding has not occurred because the performance of NLP-based conversation cannot meet the requirements of college courses. In a fully online course with formal learning objectives, the knowledge in a college course is much broader and deeper than the knowledge in K-12 courses. In addition to the requirement that virtual tutors should provide accurate and useful domain knowledge, the support provided by digital scaffolding must be in the “right amount” is still a big challenge for NLP-based conversation. Once the support provided by technology cannot fulfil the fading characteristic, that is, the decrease in assistance when the competence of the student increases (Wood et al., 1976), the product cannot be evaluated as qualified.

This study

This paper proposes a design model of fully online courses that tackle the traditional problems that online courses usually face and reduce the conflicts due to the fully online learning environment. During 2020, we implemented a successful instance of the model by conducting a fully online course named C-Programming to investigate whether and how this method would be effective in that environment. This study primarily focused on the following three research questions:

- (1) Can this technology-enhanced scaffolding instructional design result in a satisfactory pedagogical effect and efficiency for a fully online learning course?
- (2) What new online learning behavioural patterns would emerge due to this technology-enhanced scaffolding instructional design?
- (3) How can this technology-enhanced scaffolding instructional design replace the face-to-face aspect of a traditional classroom in a fully online course?

Method

Participants

Two hundred and fifteen first-year college students in China participated in fully online learning in the spring semester of 2020. The participants studied the course at home; they were aged 18–19 (mean = 19.4 years, standard deviation = 0.65; female = 117, male = 98). Their performance was compared to the performance of 232 predecessors (mean = 19.2 years, standard deviation = 0.43; female = 120, male = 112)

who studied the same course in blended teaching mode (face-to-face formal teaching plus SPOC platform) the year before. All participants majored in educational technology. Their entrance scores showed no significant differences. To clarify their differences in the following sections, the students who received fully online courses were labelled as the experimental group, and those who received the blended class were the control group. Ethical approval was not required for this study.

Instructional design

As discussed above, the design must carry three functions of scaffolding: dynamic assessment, providing the right amount of support, and intersubjectivity. However, because communications can only be fulfilled by distance, three problems inevitably become more prominent than usual, and teachers who want to conduct scaffolding in a fully online class should solve these difficulties:

- It is more difficult for teachers to guarantee and evaluate learners' engagement in a distant learning environment, even if students are provided with individualised assistance. In a face-to-face or blended class, the degree of engagement of the students can be observed by teachers through face-to-face interactions; as a result, teachers can make timely interventions. However, in an exclusive distance learning environment, behavioural data recorded by technological tools can hardly reflect the truth because the data may not be accurate; for example, using recorded videos to impersonate real learning scenes or using talking head models to impersonate someone. In complex computer-based learning environments, students are often incapable of adequately regulating their learning (Azevedo et al., 2010).
- It is harder for teachers to accurately diagnose the assistance that is truly needed by students as communications at a distance may generate misunderstanding when a situated knowledge paradox occurs. Situated knowledge paradox refers to the phenomenon that students utilise conceptual scaffolds in reading complex information and externalising their prior knowledge on the problems by finding cues and hints relevant to background knowledge. Consequently, this prevents learners from asking correct questions due to insufficient prior knowledge (Hannafin & Land, 2000).
- The contradiction between providing customised assistance for a student and the time a teacher spent on the consultation is sharper because students' learning difficulties and obstacles may vary due to their different online learning abilities and learning styles (Yang et al., 2014) and degrees of technological acceptance. The highly varied cognitive perceptions of the students may require teachers to provide individualised instead of modular assistance, and the high time cost is unaffordable for teachers.

We designed three corresponding strategies to cope with the above difficulties.

Strategy 1: Using stage-wise evaluation to stimulate learners' engagement

To maintain students' engagement, we used staged assessments. We conducted a stage-wise evaluation after the first, second and third quarters of a semester. The stage-wise evaluation was also a formal examination, which counted towards credit for the course. Therefore, it was the primary driving force for learners to form a learning circle, as shown in Figure 1.

Strategy 2: Utilising concept-experience cycles to generate high-quality conversations between teachers and students

Sufficient conversations are necessary if teachers want to provide accurate diagnoses and assistance to students (Belland, 2017); however, sufficient conversation and limited consultation are two mutually exclusive requirements. Thus, the quality of the conversations determines the time cost of the consultations. The first principle of this strategy is that null conversations should be avoided as much as possible. Null conversation refers to the misunderstood conversations between students and teachers, where (for example) the conversations cannot reach the kernel of the problem. Commonly, students cannot accurately describe what they want because of the situated knowledge paradox. In addition to their differentiated prior knowledge background, the distance learning environment worsens the situated knowledge paradox problem.

Kim and Hannafin (2011) suggested that experience cycles focused on different facets may reshape learners' perceptions of the targets. Our study required students to perform hands-on exercises in a SPOC and the experiments on EduCoder asynchronously in cycles according to their individual learning progress;

that is, they could repeatedly perform the exercises and experiments. Teachers could then intuitively understand the degree to which students had learned about a concept through repeatedly proposed task or problem-oriented questions.

However, because the exercises and experiments can be implemented asynchronously and repeatedly, students' progress may diverge greatly from one to another. This may incur an unaffordable time cost for the consultation. Thus, consultations are scheduled in a fixed time window, in which the teacher responds to each student individually. With the help of communication traces recorded by a technological tool, the teacher can quickly recall the assistance trajectories that have already been provided for that student. Moreover, the stage-wise examination further improves the efficiency of the conversation, as most students are forced to propose questions before a stage examination. In this strategy, stage-wise examinations, exercises, and experiments cross-referenced to each other formed the base of the conversation.

Strategy 3: Using a sequentially ordered resource list as a heuristic instruction for students instead of providing domain-knowledge support

There are two advantages of using a portal of a Web 2.0 resource URL list for students instead of directly providing them with domain knowledge. First, it can effectively reduce the time cost that a teacher must spend on each student's consultation. Second, the list of specifically related resources and their URLs in a sequential order means that the portal is a scaffolding instruction for students. This strategy exactly satisfies the requirement of "giving the right amount of support" to students (Belland, 2014, p. 506).

Based on the above three strategies, we proposed a scaffolding instructional design for students and teachers, and the instructional design flowchart and related technological tools are illustrated in Figure 1. First, before the formal study, students are required to conduct a self-learning session, in which they pre-learn the contents, and this phase is labelled as ①. Then, learners must participate in formal learning within a fixed time window; this step is labelled ② and ③. This learning phase is divided into two parts: the first part delivers the knowledge and related experimental models to students (②), and the second part provides one-to-one assistance for students (③). After the formal learning phase, students must implement hands-on experiments and exercises asynchronously (④) before entering the next formal learning phase. Cycles from ① to ④ constitute an integrated learning process labelled ⑤. When students finish ⑤, they are required to take a stage-wise evaluation, labelled ⑥. The semester is divided into four stages; thus, students undergo three stage-wise evaluations by before they receive the final examination.

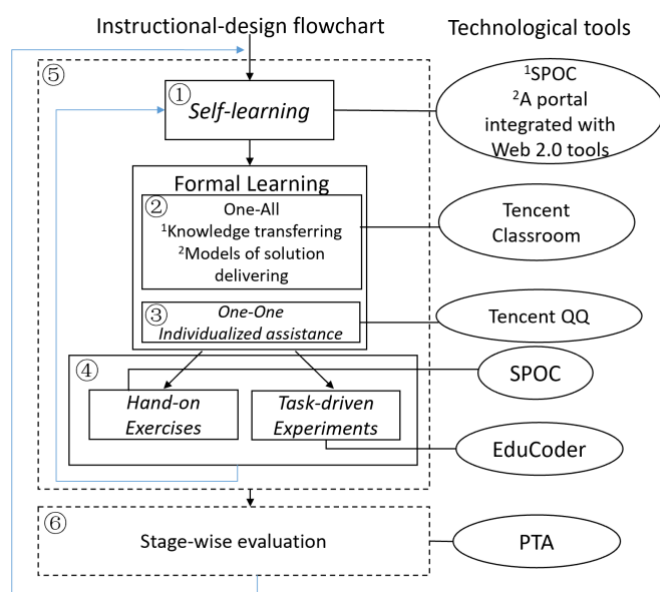


Figure 1. Instructional design flowchart and digital tools

Note. Italic-labelled activities refer to asynchronous activities; that is, activities could comprise dynamic scaffolding instructions, while others are synchronous activities. Lines with arrows refer to the direction of a cycle, and ovals represent the technological tools used to implement the corresponding activities.

Technological tools

We used the following six tools in the study.

- A SPOC is an instance of MOOC developed for learners with similar knowledge backgrounds. SPOCs are also deployed on MOOC platforms and have the same functions as MOOCs, except that they are open only to students who are invited to participate. SPOCs are typical web courses (Blankley et al., 2019). In this study, a SPOC was deployed on the University MOOCs of China (<http://www.icourse163.org/>), in which exercises and lecture videos were available for students.
- Web 2.0 mainly refers to different kinds of open resources, for example, Baidu Encyclopedia (<https://baike.baidu.com/>, similar to Wikipedia), free course videos on Bilibili (<https://www.bilibili.com/>, similar to YouTube), and blogs related to specific concepts. By using Web 2.0, students can compensate for and reshape the perceptions related to target knowledge following the scaffolding instructions provided by the teacher. As shown in Figure 1, Web 2.0 tools comprised a major part of the scaffolding. In the dialogue process, students propose their questions, and the teacher analyses the conversation and diagnoses the weak point of the learners' perception of the targets. Then, the teacher provides scaffolding assistance with a list of selective Web 2.0 resources, SPOC resources, hand-on exercises, and experiments in sequential order.
- Tencent Classroom (<https://baike.baidu.com/>) is a free synchronous collaboration tool developed by Tencent, in which teachers can synchronously share audio, text, and presentation slides. It also has functions such as hands-up and roll calling. Most importantly, it can seamlessly switch to Tencent QQ, a social communication tool. This character makes it superior to Moodle, whose drawback is the lack of social functions (Aljawarneh, 2020).
- Tencent QQ (<https://im.qq.com/index>) is a free instant communication tool that allows users to communicate synchronously and asynchronously in one-to-one and one-to-all modes. It also allows users to organise different teams to share large files and publish notices. It is used to implement conversations between teachers and students and deliver scaffolding instructions from teachers to students. A distinct characteristic that makes it significantly important in fully online scaffolding is that it can synchronise all of a learner's communication traces to different devices (e.g., computers, iPads, mobile phones). This suggests that users can communicate with others with information e-devices anywhere and anytime. The communication traces form individualised trajectories for each student's scaffolding process. After delivering the knowledge to recipients through Tencent Classroom, teachers publish public files, exercise lists, and experiment notes through team messages, which will also be kept together with their one-to-one messages.
- EduCoder (<https://www.educoder.net/>) is a heterogeneous architecture practice runtime environment that can provide simulated experimental environments for computational experiments. EduCoder allows students to use a desktop computer or tablet to implement the computational experiments at a distance. Additionally, the running and the judging of the programmes coded by students is automatically implemented by the platform.
- Pintiya (PTA; <https://pintia.cn/>) is a teaching assistant platform, which helps teachers to distantly implement stage-wise evaluations. It helps teachers create online quizzes and examinations, covering all difficulty levels and quiz types. Teachers can dynamically choose exam questions from a course pool and construct an examination for students according to different needs, for example, examinations covering different learning topics and with different difficulty levels.

Learning content of the SPOC in this study

The learning content of the SPOC was a course named C-Programming. There were three knowledge models delivered sequentially to the students:

- Introduction to programming and basic I/O, consisting of four topics: Why learn C; Data types; Simple computation and presentation; Keyboard input and screen output
- Programming designing methods and problem-solving model, consisting of three topics: Selection structure; Loop structure; Functions
- Algorithms and basic data structures model, consisting of five topics: Array; Pointer; String; Dynamic data structures; File operation.

Results

Learning effect comparison between blended learning and scaffolding-based fully online learning

This part is focused on answering research questions 1 and 2. Students in the control and experimental groups had final examination scores (FESs), SPOC exercise scores (SESs), and behaviour data (the number of videos watched, the number of posted discussion topics, and the number of comments made on a topic). FESs of the control group were collected from an examination (off-line) held before the COVID-19 pandemic, FESs of the experimental group were collected from PTA, and SES and behaviour data were collected from the SPOC platform. A *t*-test comparison between the two groups' data was conducted, and the results for different variables are shown in Table 1.

Table 1
T-test comparison between the two groups regarding FES, SES and related learning behaviour data in the SPOC

Factor		Control group (<i>n</i> = 232)		Experimental group (<i>n</i> = 203)		Sig.	Cohen's <i>d</i>
		Mean	SD	Mean	SD		
FESs		66.48	18.66	71.19	21.91	.016*	.23
SESs		44.45	29.91	63.82	32.92	.000**	.62
Learning behaviour data recorded by SPOC platform	No. of videos watched (<i>N_v</i>)	64.04	55.21	86.31	57.68	.000**	.39
	Time spent watching videos (<i>T</i>)	637.05	578.09	497.7	424.87	.04*	.27
	No. of posted discussion topics (<i>N_d</i>)	1.13	2.45	0.2	0.57	.000**	.52
	No. of comments on a topic (<i>N_c</i>)	13.19	22.16	26.3	37.13	.000**	.43

**Sig.* < .05, ** *Sig.* < .001, *d* < 0.3 (small effect); *d* = 0.5 (medium effect); *d* > 0.8 (large effect)

First, the FES and SES were significantly improved because of the scaffolding design, although most of the effect sizes were medium. Second, the students in the experimental and control groups showed significantly different patterns of using the SPOC platform. In the blended learning mode, students showed significantly higher *T*, *N_d*, and significantly lower FES, SES, *N_v*, and *N_c* than in the fully online mode. The results suggest that students in the fully online learning group showed higher learning efficacy and efficiency than their predecessors. They decreased the time watching a single video (*T*) and increased the number of videos watched (*N_v*). The decreased *T* and increased *N_v* suggest that students in the experimental group located the videos and the contents in a video more accurately than their predecessors with the help of the scaffolding instructions given by the teacher.

Students in the experimental group reduced the number of questions published on the platform while increasing their comments on their peers' published questions. This suggests that students in the experimental group received sufficient individualised support from teachers, reducing their chances of issuing assistance requirements to peers and stimulating their engagement in helping their peers in public.

Inter-correlations among variables in fully online learning

To answer research question 2, we conducted two inter-correlation analyses for the experimental and control groups. Factors such as FES, SES, number of videos watched (*N_v*), time spent watching videos (*T*), number of issued discussion topics (*N_d*) and number of comments made on a topic (*N_c*) were used for the control group. In the experimental group, in addition to the factors shared by the control group, stage-wise PTA scores (PTA₁, PTA₂, PTA₃) and EduCoder scores (ECS) were also included.

Tables 2 and 3 list the Pearson correlation analysis for the two groups; unsurprisingly, all data related to SPOC in the control group have significant correlations with their FESs. These results suggest the

effectiveness of SPOC in improving the quality of teaching in blended learning mode; however, the situation changed in fully online learning. Although SES and N_v were still highly correlated with FES, ECS and PTA scores showed higher correlations with FES in the experimental group. Moreover, the video watching time (T) was no longer significantly correlated with FES.

Table 2
Pearson correlation analysis for the control group

	FES	SES	N _v	T	N _d	N _c
FES	1	.316**	.151*	.157*	.203**	.228**
SES	.316**	1	.723**	.696**	.340**	.488**
N _v	.151*	.723**	1	.938**	.215**	.477**
T	.157*	.696**	.938**	1	.184**	.407**
N _d	.203**	.340**	.215**	.184**	1	.315**
N _c	.228**	.488**	.477**	.407**	.315**	1

*Sig. < .05; **Sig. < .01; ***Sig. < .001

Table 3
Pearson correlation analysis for the experimental group

	FES	SES	N _v	T	N _d	N _c	ECS	PTA ₁	PTA ₂	PTA ₃
FES	1	.547**	.321**	.110	.209**	.260**	.609**	.460**	.567**	.533**
SES	.547**	1	.540**	.284**	.242**	.448**	.729**	.408**	.459**	.425**
N _v	.321**	.540**	1	.468**	.210**	.599**	.379**	.148*	.218**	.202**
T	.110	.284**	.468**	1	.141*	.265**	.177*	-.014	.108	.107
N _d	.209**	.242**	.210**	.141*	1	.317**	.150*	.102	.130	.132
N _c	.260**	.448**	.599**	.265**	.317**	1	.295**	.192**	.175*	.176*
ECS	.609**	.729**	.379**	.177*	.150*	.295**	1	.497**	.577**	.481**
PTA ₁	.460**	.408**	.148*	-.014	.102	.192**	.497**	1	.646**	.510**
PTA ₂	.567**	.459**	.218**	.108	.130	.175*	.577**	.646**	1	.755**
PTA ₃	.533**	.425**	.202**	.107	.132	.176*	.481**	.510**	.755**	1

*Sig. < .05; **Sig. < .01; ***Sig. < .001

Experimental factor analysis in measuring learners' academic achievement

To answer research question 3, we conducted an exploratory factor analysis of the following items to measure learners' FES: SES, N_v, T, N_d, N_c, ECS, PTA₁, PTA₂ and PTA₃. Using exploratory factor analysis with principal component analysis and varimax rotation, we discovered two factors with eigenvalues above 1. Candidate items with a mean squared error above 0.5, in the anti-image correlation matrix, are considered as components of factors, suggesting that all except N_d could be represented by the factors. The first factor (composed of ECS, PTA₁, PTA₂ and PTA₃) represents the effects of EduCoder and PTA. The second factor (SES, N_v, T and N_c) represents the effect of SPOC. The first factor explains 41.92% of the variance, and the second factor explains 18.78% of the variance. Table 4 presents the factor analysis results for FES.

Table 4
Principal component analysis: Final examination score (FES)

	Factor 1: EduCoder + PTA	Factor 2: SPOC
SES	.820	.134
N _v	.624	.583
T	.365	.552
N _d	.339	.311
N _c	.564	.530
ECS	.800	-.137
PTA ₁	.654	-.472
PTA ₂	.761	-.473
PTA ₃	.704	-.429

Multiple regression models of learners' academic achievements

The experimental factor analysis revealed that learners' final examination achievement in this course could be explained by two major factors. However, we still do not know how those factors replace the face-to-face part in predicting learners' learning outcomes in an exclusively online class. In this section, we performed a fixed-order stepwise multiple regression analysis for both blended and fully online learners based on their learning data, with FES as the dependent variable and SES, N_v , T , N_d , N_c , ECS, PTA_1 , PTA_2 and PTA_3 as candidate predictors. Table 5 presents the proportions of variance with the FES as the dependent variable.

Table 5

Proportions of variance with the final examination score (FES) as dependent variable and SES, N_v , T , N_d , N_c , ECS, PTA_1 , PTA_2 and PTA_3 as candidate predictors for the experimental group and the control group, respectively

Dependent variables	Proportion of variance accounted for (%)						
	Step1:	Step2:	Step3:		Step4:		
	ECS	PTA_3	Increment	SES	Increment	PTA_2	Increment
FES (experimental group)	.371	.446	.075*	.460	0.014*	.472	0.012*
FES (control group)	Step1: SES	.100					

*Sig. < .05; **Sig. < .01; ***Sig. < .001

Two regression models were generated for the experimental and control groups. The model for the control group had only SES as its predictor, with $R^2 = 0.32$; and the model for the experimental group had four predictors (ECS, PTA_3 , SES, and PTA_2), with $R^2 = 0.47$. The regression model of the fully online learning suggests that the hands-on experiments in the scaffolding design had a prominent effect on driving students to conduct scaffolding instructions. Additionally, the model demonstrates that the stage-wise evaluation gradually reshapes learners' perceptions of the targets as closer to the end of the term. Moreover, their performances on stage evaluation are closer to the performance on FES. In contrast to the experimental group's regression model, the control group's regression model is simpler, as the major part that contributes to learners' FES happened offline.

Discussion

The results indicate that students who learned in a fully online course significantly outperformed those who participated in the blended class in terms of FESs and SPOC scores with medium effect size. This promising result suggests that the technology-enhanced scaffolding design can replace face-to-face interactions in traditional and blended classes and change learners' learning behaviours. The significantly higher SPOC scores in the experimental group showed that the design also improved the effectiveness of the SPOC. Next, we discuss how the design works in fully online learning from two aspects.

First, the results reveal that the EduCoder and PTA play an important role in the fully online course, which explains 45% of the learners' FES. The stepwise regression model shows that ECS, 3/4 PTA_3 , SES, and 1/2 PTA_2 are the most important predictors of the FES, suggesting that learning occurs in concept-experience cycles (Kolb, 1984). This result indicates that the nested design (as Figure 1 illustrates) efficiently deconstructs the big learning process into four observable learning cycles, each comprising several uncountable small learning cycles driven by hands-on experiments and exercises. This nested cycle design efficiently reduces the number of Kolb cycles involved in the learning process and makes the number of cycles controllable and affordable for teachers. The stage-wise examination worked as a guard for each outer learning cycle and monitored the results, giving pressure to the inner cycles.

The nested cycles of scaffolding design in this study satisfy the requirements of the experimental learning theory of Kolb (1984) and are also a typical instance of problem-solving scaffolding in technology-enhanced learning environments (Kim & Hannafin, 2011). Kim and Hannafin suggested that interactive cycles should be integrated into scaffolding to solve the situated knowledge paradox problem. However, due to the high time cost that teachers must expend, an efficient solution regarding the situated knowledge paradox problem is lacking. The nested interactive cycles between teachers and students proposed in this study is an executive model of Kim and Hannafin's idea by repeatedly reshaping students' perceptions of the targets from three aspects: exercises, experiments, and stage-wise examination. The heuristic scaffolding instructions and modelled problem-solving procedures (Greisdorf, 2003) stimulate learners to form their internal cognition cycles (Zheng et al., 2019) through cross-referring multi-sourced questions and reflections.

Second, we discuss the successful usage of the technological tools in this fully online course. Among the 37 studies scrutinised by Sosa Neira et al. (2017), none of them targeted fully distance learning, suggesting that employing technologies to implement a fully online course is very risky. However, as pointed out by Moorhouse (2020), teaching is now forced online due to the COVID-19 pandemic. Before COVID-19, the course in this study was taught in a blended mode, that is, face-to-face + SPOC. Due to the pandemic, face-to-face interactions had to be replaced by communications at a distance. To compensate for the shortcomings of this environment, five new technological tools in addition to the SPOC platform were employed: an online conference software to organise the class and systematically deliver knowledge, an instant communication tool to implement communications at a distance and record the communication traces among teachers and students, an experiment simulator to allow students to implement the experiments distantly, an assessment tool to form flexible stage-wise examination, and open-access Web 2.0 resources to form heuristic scaffoldings. The significantly weakened effect of the SPOC suggests that other technological tools contribute the major parts to the learning results.

The technologies in this study refer to mobile learning, Web 2.0, learning technologies, digital instructions, management systems, technology-enhanced feedback system, and MOOCs (SPOC), which cover 30% of the 20 technologies referred to in the 365 papers in Lai and Bower (2019). The Web 2.0 technologies in this study include the synchronous collaboration tool, wikis, blogs, and video-sharing tool (according to Bower's classification, 2016). Therefore, our study shows that although automatic digital-scaffolding tools are still unavailable in university teaching, it is possible to construct and apply one-to-one scaffolding in technology-enhanced learning environments by sufficiently and reasonably using technological tools according to their characteristics. After all, the type of learning that results from using a tool depends on the task and how the tool is used, not on the technology itself.

Conclusion and the further work

In sum, the two-nested scaffolding instructional design for fully online courses with the assistance of appropriate technological tools is feasible and applicable. Although some of the tools are available only in China, and some are commercial products, most of them can be replaced. For example, PTA can be replaced by quizlet, Tencent Classroom can be replaced by Zoom (Bower, 2016), and Tencent QQ can be replaced by WhatsApp. Therefore, we hope that this successful pedagogical experience can be shared with as many educators as possible.

The main limitation of this study is that only one course was involved. Therefore, we are developing a standard design for this method to cope with various courses, including theoretical and practical courses. In addition, we are also developing guidance for tackling design problems, such as cheating in an online examination and plagiarising the exercise answers.

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Corresponding author: Han Su, jkxy_sh@sicnu.edu.cn

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