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Using the Online Self-Directed Learning Environment to Promote Creativity Performance for University Students

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ABSTRACT: Creativity has been identified as a critical educational goal and an essential 21st-century skill, which can be captured through learning capabilities, thinking skills, and academic achievement. Although the relationship between creativity performance and self-directed learning (SDL) was theoretically researched, few studies have thoroughly investigated the exact nature of this association from a practical perspective. Therefore, this study aimed to design an online self-directed learning environment (OSDLE) to improve students' creativity performance. The OSDLE was proposed with functions such as planning, learning, evaluation, and reflection, based on the three dimensions of personal attributes, process, and learning context. A quasi-experimental study was conducted in a university in Northeast China to explore the influence of the OSDLE on creativity performance. One hundred and six university students as study participants were randomly assigned to experimental and control groups. Participants in the experimental group learned in the OSDLE, whereas those in the control group learned in traditional classroom methods. The results indicated that the students using the OSDLE exhibited significant improvements in creativity performance. Furthermore, the SDL capabilities of the experimental group demonstrated gradual and continuous improvement. In addition, students' thinking skills and academic achievement in the experimental group were higher than those of the control group. The main findings together are discussed in depth.

Keywords: Creative learning, Self-directed learning, Creativity performance, Online self-directed learning environment

1. Introduction

Creativity is considered as one of the crucial competencies required for students to survive and thrive in the 21st century (Hong & Song, 2020; Hernández-Torrano, & Ibrayeva, 2020). The rapid advancement of technologies has increased active learning opportunities for novices and experts, and the complexity of this landscape means that creative students must become independent learners and exhibit a general trait of self-direction (Tekkol & Demirel, 2018; Garrison, 1997). When students are increasingly expected to be responsible for their learning, self-directed learning (SDL) can serve as an essential component of creative activity (Lemmetty & Collin, 2021; Lee, 2019; Yeh & Lin, 2015). Although it has been repeatedly asserted that creative experiences and achievements are associated with SDL (Morris, 2020; Torrance & Mourad, 1978), the exact nature of this association remains unclear. Therefore, examining the possibility that creative learning outcomes can be supported through SDL is an urgent concern (Gralewski & Karwowski, 2019).

Amabile (1982) stated that the outcome of the creative process and the process of creativity could be applied to facilitate the measurement of creativity interchangeably. From the outcome perspective, thinking skills are mainly identified as originality, flexibility, and fluency of thinking, generally considered reliable indicators of creativity (Guilford, 1967). Empirical studies have proved that thinking skills and the creation of creative products are positively correlated (Hardy et al., 2017; Morris, 2020). Hence, improving students' thinking skills is essential to support the individuals' development in creativity performance.

Meanwhile, a widespread belief is that creativity relies on a learner's knowledge, which views as an information source for creativity (Amabile, 1982). Investigations have indicated a positive correlation between creativity performance and academic achievement. Relevant knowledge is the foundation for scientific creative activities, including identifying scientific problems, designing scientific experiments, and more (Klahr & Dunbar, 1988). Hence, students with expertise in a field can better retrieve information they need and make connections to other information previously learned, which lays a solid foundation for creativity.

Notably, SDL capabilities can be viewed as a prerequisite for promoting creativity performance (Lemmetty & Collin, 2021; Morris, 2020). Lee (2019) used repeated measures mixed model analysis and hierarchical linear model analysis to demonstrate that SDL improved students' creative abilities, but the explanation of this relationship is unclear. In this regard, Morris (2020) conducted a literature review and highlighted that SDL supports creative learning outcomes. Specifically, when individuals with SDL capabilities can be open to new ideas, they may be able to view knowledge in a different and creative way (Toh & Kirschner, 2020).

In addition, Smith (2009) emphasized that online platforms can facilitate an environment that supports independent learning and enhances participative behaviors and possibly even creativity. According to Mishra et al. (2013), students in school lack the opportunity to navigate complex exploration and creativity performance because of the bounded designs of the traditional classroom. They theoretically stated that “open-ended, technology-rich learning contexts appear to provide opportunities for students to be structured in their ways of thinking” (Mishra et al., 2013), which is the crux of creativity. Although the online environment can help students enrich their learning experience, an unwanted consequence is that it can disturb students’ creativity processes if they lack proper SDL capabilities. Based on the studies of the role of SDL practices in creative activity in a technological context (e.g., Lemmetty & Collin, 2021), online learning environments are proved to be more effective at promoting SDL (Candy, 1991), which can provide opportunities for students to foster innovative thinking (Mishra et al., 2013). However, it is no longer enough to simply explore the improvement of creativity by the SDL environment from a theoretical perspective. Therefore, it is necessary to provide an online self-directed learning environment (OSDLE) in school settings to prepare students for creativity during the learning process.

In this study, an OSDLE was designed with four modules, and its effects on students’ creativity performance were assessed through analyzing their SDL capabilities, thinking skills, and academic achievement. Section 2 reviews the literature on creativity in online learning and presents the conceptual framework for SDL in the online learning environment to situate the study. Section 3 describes the OSDLE developed in this study. In Sections 4 and 5, the experiment and results evaluation are demonstrated. Finally in Section 6, after the research findings are discussed, conclusions and suggestions for future research are presented.

2. Literature review

2.1. Creativity

Creativity plays a crucial role in further developing human intellectual potential, and the interest in creativity within the scope of education has grown exponentially (Hernández-Torrano, & Ibrayeva, 2020). The growth in interest is due mainly to creative thinkers being able to adjust easily to new situations and create new and original ideas that are considered useful or valuable by integrating the knowledge, skills, and experience of diverse professional fields (Chiu & Tu, 2014; Rhodes, 1961). Therefore, the concept of creativity is complex and challenging to define in the research field because creativity is no longer a single attribute, but rather a set of attributes (Sternberg, 2006). According to Ma (2009), personal factors can be applied to define a person’s creativity, including personality, cognitive ability, thinking style, and academic achievement.

Previous studies have analyzed person-centered variables that contribute to creativity. From a more holistic perspective, many studies on creativity have adopted approaches to investigate different aspects of creativity, such as Rhodes’s (1961) “four P’s of creativity,” which means person, process, product, and press. Isaksen et al. (1993) explained the simultaneous interaction among “four P’s” components. This model highlights the “creative process” as an integral part, emphasizing the interactions among the components related to individuals and environments. Therefore, the generation or manifestation of creativity performance can be captured through SDL capabilities, thinking skills, and academic achievement.

Since its inception, creativity research has been linked to education (Hernández-Torrano, & Ibrayeva, 2020). Fostering creativity has attracted much attention in the field of education (Chiu & Tu, 2014). Creativity can be regarded as a practice-based process wherein it is essential for students to actively engage in the creative process (Dewey, 1916). Consequently, the practices of SDL appear to match these demands. Tekkol and Demirel (2018) used the survey method and concluded a moderate positive relationship between SDL and creativity. This relationship is also found in Lee (2019) and Lemmetty and Collin (2021). However, few attempts have been made to design the OSDLE to improve creativity. To cultivate students’ creativity, constructing an environment that enables students to SDL and implement learning strategies flexibly to generate new ideas is necessary. Therefore, the OSDLE can be considered an effective way to promote creativity performance.

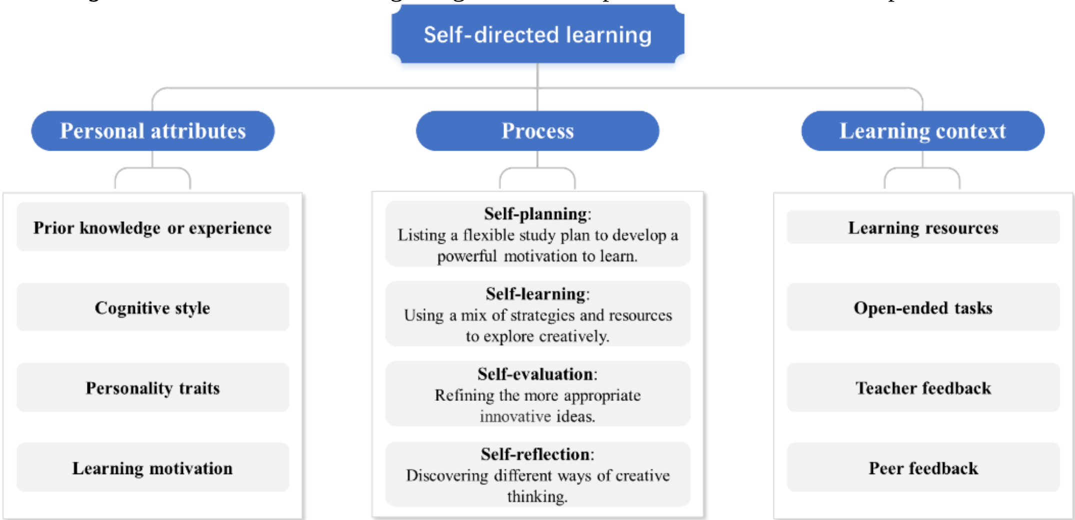
2.2. Self-directed learning

SDL was previously defined as the process of an individual actively learning with or without the assistance of others (Knowles, 1975). Guglielmino (1977) proposed another definition and posited that personal attributes determine whether an individual has the ability and potential of SDL. The definition of SDL has also been accompanied by the concept of self-regulated learning, yet SDL is a broader concept that involves the use of self-regulated learning strategies, including planning, monitoring, and evaluation (Dickinson, 1987; Manganello et al., 2019; Rubenstein et al., 2018). However, given that a student does not learn nor act individually, previous studies on SDL showed that the external learning context could play a role in SDL development (Chu et al., 2012; Kim et al., 2021; Mamun et al., 2020). Therefore, SDL commonly considers not only the process and personal attributes but also the importance of learning context.

Subsequently, numerous conceptual models for SDL were developed to better understand and foster SDL in the learning environment, including Candy's (1991) Four-Dimensional Model, Garrison's (1997) Three-Dimensional Model, and Song and Hill's (2007) Conceptual Model. Despite the differences among these models, they are significantly overlapped regarding the critical constructs associated with each model (Morris & Rohs, 2021). In most of the SDL models reviewed, personal attributes, process, and learning context were discussed to a certain extent (Song & Hill, 2007).

Regarding creativity, Song and Hill's (2007) model places greater emphasis on the online learning context factor, and the clear learning process, which may more accurately introduce a conceptual model to understand SDL in an online environment while creating. Moreover, recent research indicated that students need to have a high level of SDL capabilities to successfully develop the ability to think creatively (Morris, 2020). SDL enables individuals to change their mode of learning from "passive study" to "independent study," thereby improving their creativity performance. Therefore, we present the conceptual framework of SDL and describe how one can facilitate creativity during the process (Figure 1).

Figure 1. A framework of integrating the creative process into an SDL conceptual model



2.2.1. Personal attributes

Personal attributes are described as characteristics of students in a specific learning situation (e.g., prior knowledge or experience, cognitive style, personality traits, and learning motivation). Specifically, the relationship between personal attributes and creativity has been assessed by many scholars (Amabile, 1982; Sternberg, 2006). Suppose the level of students' personal attributes is high. In that case, they tend to retrieve knowledge better, exhibit independent judgment, are highly self-disciplined, and remain enthusiastic for learning (Morris & Rohs, 2021), making it easier for students to perform creative behaviours or achieve innovative results outcomes.

2.2.2. Process

The process focuses on students' autonomous learning process (Song & Hill, 2007), including self-planning, self-learning, self-evaluation, and self-reflection stages. During the self-planning phase, students list a flexible study plan to identify learning goals and a way forward. It stimulates each student to develop a powerful motivation to learn (Tang et al., 2020). The self-learning phase provides an opportunity for students to creatively explore the task at their pace using a mix of strategies and resources (Hardy et al., 2017). During testing and monitoring, students move through phases of self-evaluation and self-reflection. These phases refine the more appropriate innovative ideas and require students to critically evaluate their decisions when reflecting on the learning process (Yeh & Lin, 2015), which can support students in discovering different ways of creative thinking.

2.2.3. Learning context

The learning context has various factors that can affect the development of SDL capabilities, including the learning resources, open-ended tasks, and feedback from the teacher and peers (Song & Hill, 2007). Sufficient learning resources and open-ended tasks permit students to access updated cognitive. Additionally, students may benefit from critical and constructive feedback, which in turn contributes to promoting creativity performance.

2.3. Research motivation and questions

In light of the literature reviewed, despite a convincing theoretical rationale that creativity and SDL are positive attributes (Mishra et al., 2013; Lemmetty & Collin, 2021), research on teaching practicum-relevant outcomes that can be included in SDL to promote creativity is scarce. Moreover, whereas prior researches have indicated that the nature of creativity is definitionally difficult to capture and identify (Gralewski & Karwowski, 2019; Ness, 2012), less attention has been given to understanding creativity-related variables, such as learning capabilities, thinking skills, and academic achievement. Therefore, the study expands on previous research focusing on improving creativity as a motivational consequence of designing an OSDLE. The assessment of creativity demands multiple avenues of measurement because it is a multidimensional concept. Therefore, this study investigates students' creativity by exploring and examining their SDL capabilities, thinking skills, and academic achievement. The present study was guided by the following research questions:

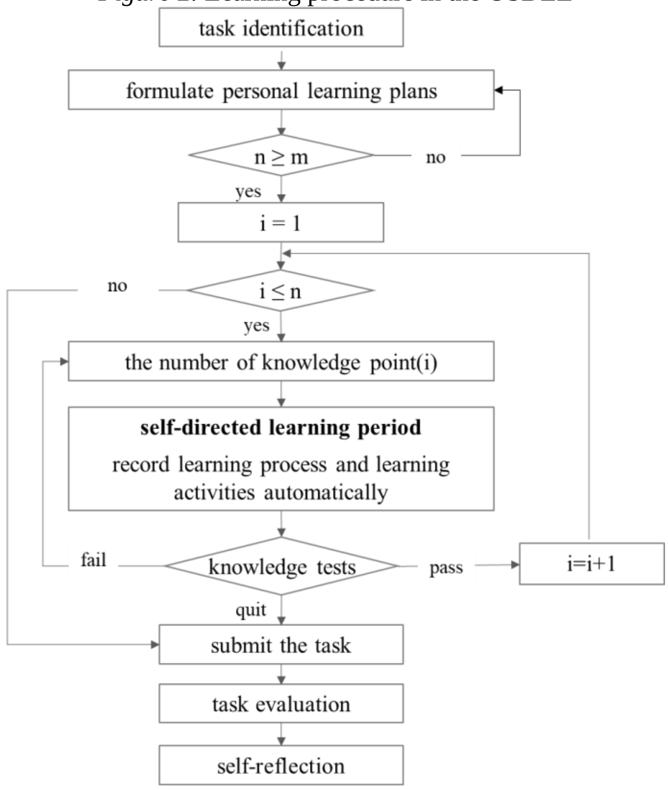
- RQ1 - Do students enhance their SDL capabilities by learning in the OSDLE?
- RQ2 - Do students who learn in the OSDLE show better thinking skills than those who learn in traditional classroom methods?
- RQ3 - Do students who learn in the OSDLE show better academic achievement than those who learn in traditional classroom methods?

3. Design of online self-directed learning environment

3.1. Learning procedure in the OSDLE

The learning procedure of the proposed OSDLE is shown in Figure 2, where m is the minimum number of knowledge-learning points required to be learned set by the course teacher to complete the specific learning task. Students first view the learning task and formulate a definite learning plan based on their learning experience and previously accumulated knowledge, where n is the number of planned knowledge-learning points set by students. Then, each knowledge learning content is embedded in the Q&A module and an evaluation module. The tests consist of a set of two-tier multiple-choice questions. Each test item has three or four choices in the first tier, and there are three or four reasons for each choice in the second tier (Yang et al., 2015). Each test item was developed and reviewed by domain experts and researchers (r = 0.88). To consider a question as correctly answered, students need to be answered correctly in both tiers. An example of a two-tier test item is shown in Appendix Figure 11 and Table 5. After passing the knowledge test, students can enter the next knowledge point for learning; otherwise, a continued revision of this knowledge point is suggested until the test is passed. Moreover, if students want to quit further learning, they can choose to submit the task directly. Additionally, students could evaluate peers' tasks, observe excellent artifacts, and share reflection logs based on the learning behaviour assessment form.

Figure 2. Learning procedure in the OSDLE



3.2. OSDLE function module

The OSDLE includes four modules: planning, learning, evaluation, and reflection. Students make their learning plans based on learning context and tasks. Then, the OSDLE receives students' learning plans from the planning module, deploys the tasks on the learning module, monitors their progress, reconfigures the learning tasks based on learning needs and evaluation results, and reports status and results to the evaluation module. The following subsections demonstrate the details of the modules in the OSDLE.

3.2.1. Planning

In the planning module, students need to fill in the K-W-L (know, want to, learn) chart, where K means what we know, W means what we want to know, and L means what we learned and still need to learn (Ogle, 1986). During step K, the teacher can discover what the students do not know, and then provide relevant learning materials. Step W helps students develop clear personal goals. The majority of step L involves promoting students' reflection. To lay the foundation for calculating SDL capabilities, students also need to set up the planned learning time and knowledge-learning points. In general, when students decide on the need for guidance, they may overcome procrastination in online learning (Shadiev et al., 2018), which urges students to create new ideas actively.

3.2.2. Learning

The learning module consists of three sub-modules: learning content, monitoring, and Q&A. To support students in identifying their academic strengths and weaknesses, the OSDLE divides the learning content module into three parts: learning, learned, and not learned.

Extensive knowledge or ability in learning is the basic foundation for creativity performance (Amabile, 1982). When using the OSDLE, students are not passive recipients of knowledge, but rather seek the proper learning resources according to their needs, enabling them to have the opportunity to acquire more diversified knowledge, which may lead to creative outcomes.

Students’ cognitive structure in a specific field will be developed and improved further when actively learning task-related knowledge. Drawing from Bloom’s (1956) Taxonomy of Educational Objectives, the learning content consists of three levels: knowledge, comprehension, and application. Based on the Classical Testing Theory (Holland & Hoskens, 2003), each student’s level of learned content is ranked on a two-level ordinal scale: complete content with a green flag and incomplete content with a red flag, as shown in Figure 3.

The monitoring module displays students’ learning progress, as illustrated in Figure 4, and includes planned learning time, total learning time, actual learning time, planned knowledge-learning points, and actual knowledge-learning points. This module also shows the test score and task score. These various design indicators are used to calculate SDL capabilities and performance. Moreover, the monitoring module provides visualization of progress toward the learning goals to help students reflect on their learning and plan their next steps, which can be seen as a stimulus for creative activity.

Figure 3. The screenshot of learning module

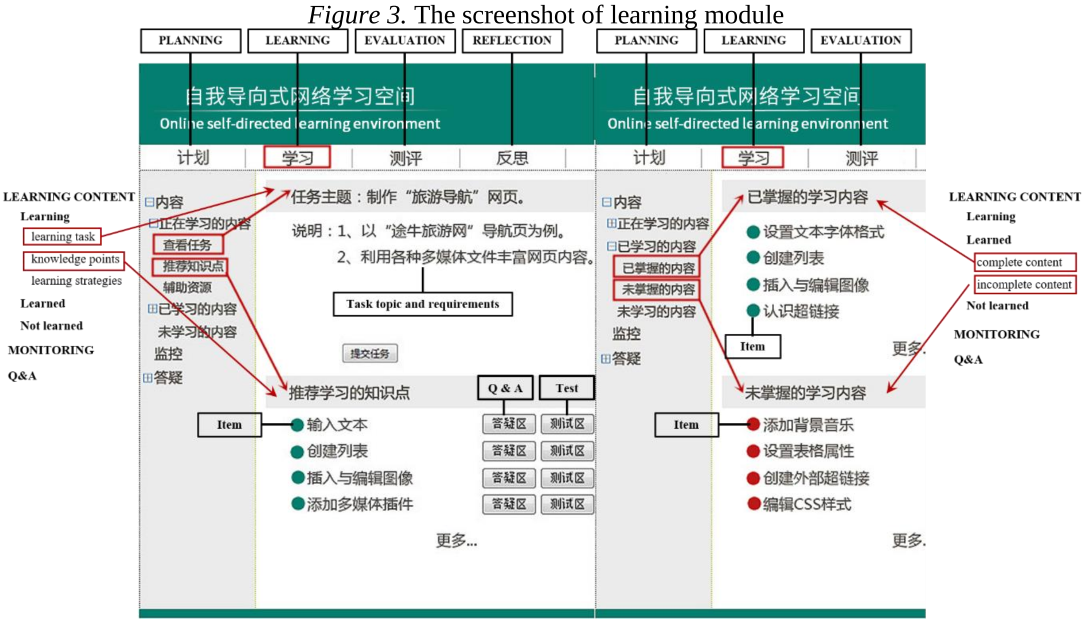
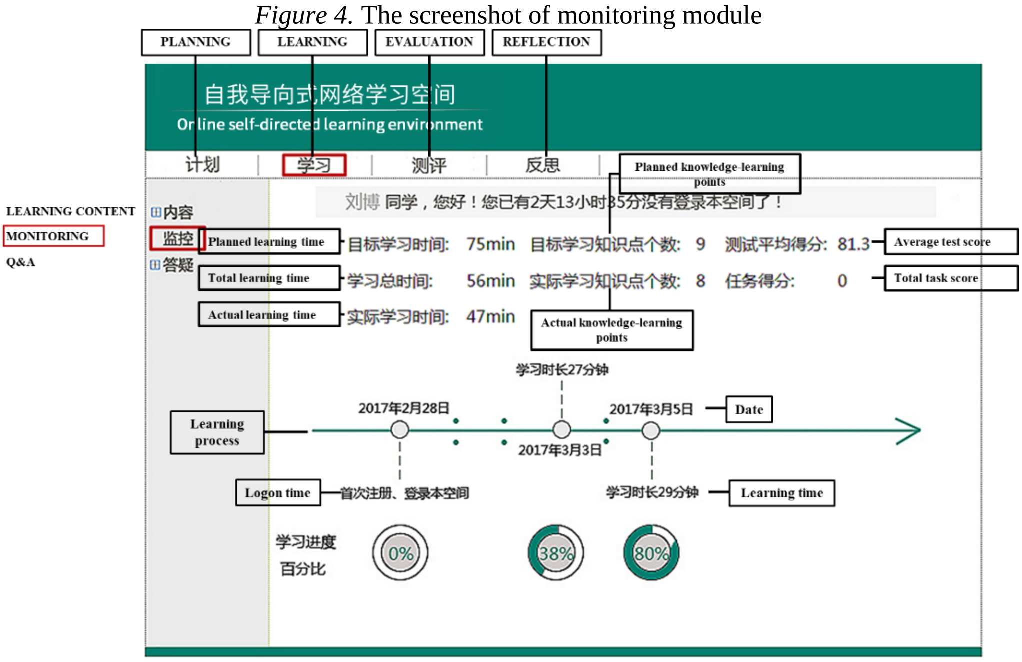


Figure 4. The screenshot of monitoring module

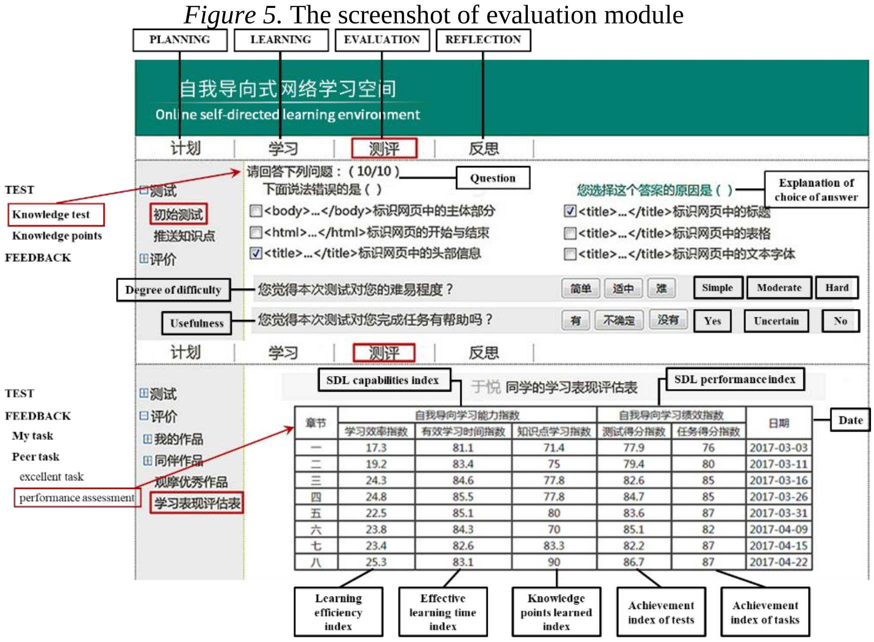


The Q&A module allows all students to share and discuss different opinions and thoughts. After the question is answered, and to reduce the uncertainty of peer knowledge, students can choose to close the question or keep the question open based on their judgment on the correctness of the answer. Meanwhile, the teacher can understand the primary problems by checking and answering students’ queries. As students discuss the questions, creating a coherent or compelling argument may compel them to identify gaps in their knowledge and to retrieve and modify their existing understanding with new ideas.

3.2.3. Evaluation

The evaluation module contains two parts: test and feedback. The two-tier test approach is used to identify students’ learning status, as shown in Figure 5. A two-tier test consists of a set of multiple-choice items, including the question, answer choices, and the choice for the reasons (Yang et al., 2015). Subsequently, the misconception of knowledge is identified by both answers and reasons. Meanwhile, students who have used the OSDLE can diagnose their learning weaknesses and are enthusiastic about actively reflecting on the problem-solving process to facilitate creativity.

Figure 5. The screenshot of evaluation module



The feedback part of the OSDLE includes teacher feedback and peer feedback. In particular, the role of the course teacher and peers is essential for enhancing students’ creativity. Students can view the teacher’s comments while also observing samples of excellent work produced by their peers. This domain also produces a learning performance evaluation table, as shown in Figure 5, thereby enabling students to understand the gap between their performance and others and indicating the direction for further study.

3.2.4. Reflection

In the reflection module, students can articulate what they have learned during the task and accomplish the L part of the K-W-L chart. Because reflection does not develop automatically, it can be taught through effective facilitation (Ogle, 1986). Students can critique the skills and knowledge in the OSDLE and gain space for novel ideas and possibilities to emerge, which is a fundamental skill in encouraging creativity. At the same time, students can decide whether to share reflection logs. The reflection module promotes critical inquiry, engaged dialogue, and reflective practice (Song & Hill, 2007). Additionally, students review each other’s online reflective journals in which they can reflect on their learning and bring forth creative ideas based on the habitual experience of the past.

4. Method

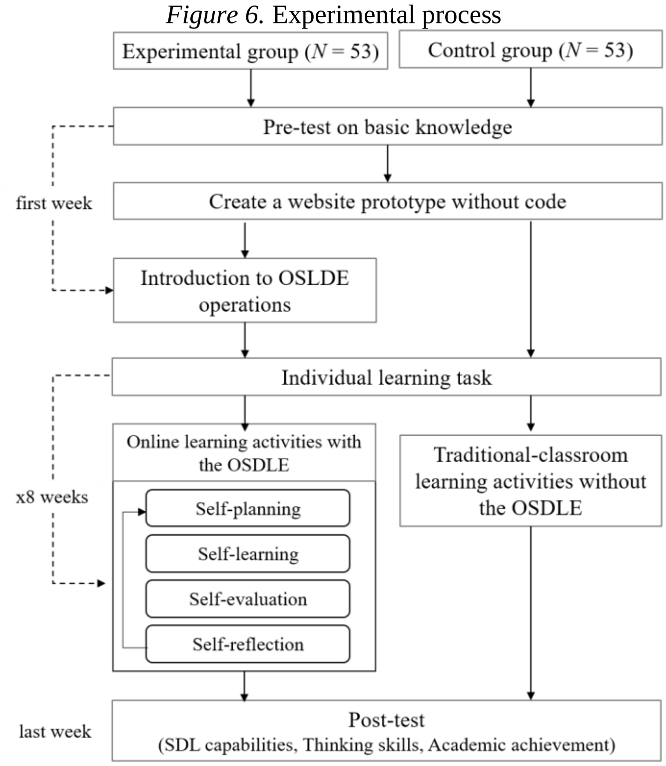
4.1. Participants

During the eight weeks of this study, 106 students at a university in Northeast China voluntarily participated. We want to mention that the original sample contained 106 university students who gave consent to use their data for research purposes. Two experiments on the course named web design and programming were conducted in two separate semesters. In this respect, all participants were randomly assigned to the two groups. The experimental group (N = 53) was assigned to the experimental condition (i.e., using the OSDLE), and the control group (N = 53) to the control condition (i.e., not using the OSDLE).

4.2. Experimental procedure

As illustrated in Figure 6, the experimental design of study is introduced. The overall activity conditions were similar in experimental and control groups.

Figure 6. Experimental process



This study started with a set of prior knowledge tests as the pre-test to evaluate the participants' original understanding of web design and programming. The results of the pre-test indicated that there was no significant difference in prior academic achievement between the experimental group and control group (p = .89). At the beginning of the testing session, each participant was informed of the study's procedure and that their data would be handled confidentially. The participants were then asked to create a website prototype with basic design and functionality without writing any code before the experiment started. Later, the experimental group received an additional introduction session on the OSDLE and was instructed to use the functions in the four modules.

Next, the experimental and control groups received the same learning tasks and goals. The activity lasted eight weeks, with one task per week and a total of eight (i.e., Make a website with the body, font, br, and hr tags). The experimental group conducted learning using the OSDLE, while the control group received traditional teaching instruction in the classroom.

After the learning activities, the two groups of students were immediately administered the post-test during regular class time and were asked to submit a designed website with code based on what they had learned within one week. Finally, four experts were invited to assess the students' products to obtain data on students' thinking skills.

4.3. Measurement

The research measurement tools included logs of the supervised learning activities on the OSDLE, creative products, and pre- and post-tests.

To investigate the SDL capabilities of the experimental group during the experiment, their learning behaviors were recorded through the modules of OSDLE, including students' online time, task score, and the number of knowledge points learned (Chen, 2009). For online time, log data included the planned learning time to complete learning tasks, the total learning time that students were logged in the OSDLE, the learning time of each module, and the actual learning time, which is the total learning time minus the idle learning time (the time when the operation of the mouse or keyboard cannot be detected within a specific period). For the task score, each task was graded based on a scoring rubric that was designed on the basis of the course syllabus. The rubric was found to be consistently used by two professors and four researchers with good inter-rater reliability (Cronbach α = 0.92), as shown in Appendix Table 6. For the number of knowledge points learned, log data included the weekly knowledge-learning points completed.

The Consensual Assessment Technique (CAT) (Amabile, 1982) was used to assess the students' thinking skills in the pre- and post-experiments. Four independent experts blind-scored all products on a 5-point scale in originality, flexibility, and fluency, where the value of 5 represented the highest level of thinking skills. In this method, three major dimensions of the criteria for rating creative products were provided, which were attached in Appendix Table 7. Originality was determined by the percentage of pages that differed from the categories covered by the reference sample. Flexibility represented an estimate of the degree of website layout friendliness. Fluency represented an estimate of how many types of functions were designed. To prevent the order effect, each judge rated the compositions in a different random order. The four experts' ratings on the three dimensions of originality, flexibility and fluency were then averaged separately to produce the students' scores on each dimension, and the average of the three dimensions was used as a measure of thinking skills for participants. To access internal consistency of the CAT's dimensions, Cronbach's alpha calculated for originality was .84, for flexibility was .80 and for fluency was .82, indicating high consistency.

To investigate the differences in participants' academic achievement, the scores of pre- and post-tests were analyzed. Both the pre- and post-tests consisted of 20 two-tier multiple-choice questions, with a total score of 100. A two-tiered question is considered correct only if both tiers were answered correctly. These tests were focused on the content of the lessons (i.e., the website design) with the same knowledge but different levels of difficulty. The pre-test with relatively low difficulty values was given to assess the students' pre-performance before the experiment, and the post-test score reflected the students' post-performance.

5. Results

IBM SPSS was applied to analyze the creativity performance of the participants, including the results of SDL capabilities, thinking skills, and academic achievement.

5.1. Self-directed learning capabilities

The SDL capabilities index includes the learning efficiency index (T1), effective learning time index (T2), and knowledge points learned index (K).

The learning efficiency index refers to the efficiency of students completing a task in the OSDLE. The formula for calculating the learning efficiency index is shown in Table 1, where t-time(s) is the s{th}student's total learning time, and p-time(s) is the planned learning time set by the s{th} student in the planning module.

The effective learning time index is the ratio between actual and total learning times. The formula for calculating the effective learning time index is shown in Table 1, where a-time(s) is the s{th} student's actual learning time.

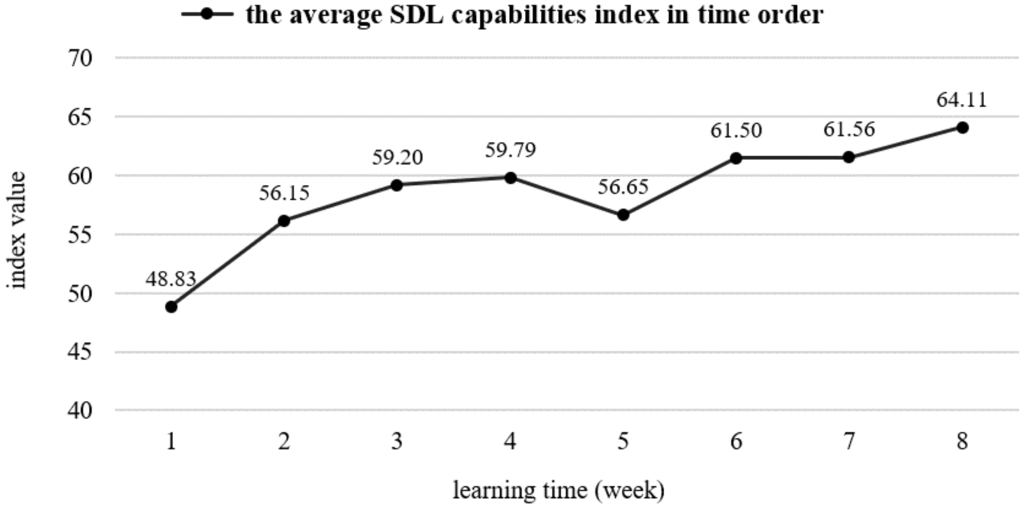
The knowledge points learned index is evaluated based on the ratio of the knowledge-learning points passed by the student in the weekly tests and the planned knowledge-learning points set by the students. The knowledge points were different every week because of different contents. The larger the value, the greater the number of knowledge point learned by the student. The formula for calculating the knowledge points learned index is shown in Table 1, where a-knowledge(s) is the amount of actual knowledge-learning points of the s{th} student during the learning process, and p-knowledge(s) is the amount of planned knowledge-learning points set by the s{th} student. When the knowledge points learned index is greater than or equal to 1, it is obtained by 1.

By analyzing the mean value of the SDL capabilities sub-index of 53 students in the experimental group, it can be seen that the SDL capabilities index of the experimental group showed a general trend of gradual improvement within eight weeks. A significant difference was observed in the experimental group's SDL capabilities to complete the first and eighth tasks (p = .005 < .05). More details of the students' statistical information of SDL capabilities are listed in Appendix Table 8. In addition to a slight decrease in the fifth week, the interview with the students in the subsequent period revealed that the fifth week was during the midterm exam, which might cause students to reduce their engagement. Therefore, the results revealed that the OSDLE had a positive effect on improving students' SDL capabilities (the average of the learning efficiency index, effective learning time index, and knowledge points learned index), as shown in Figure 7.

Table 1. Formula for SDL capabilities index

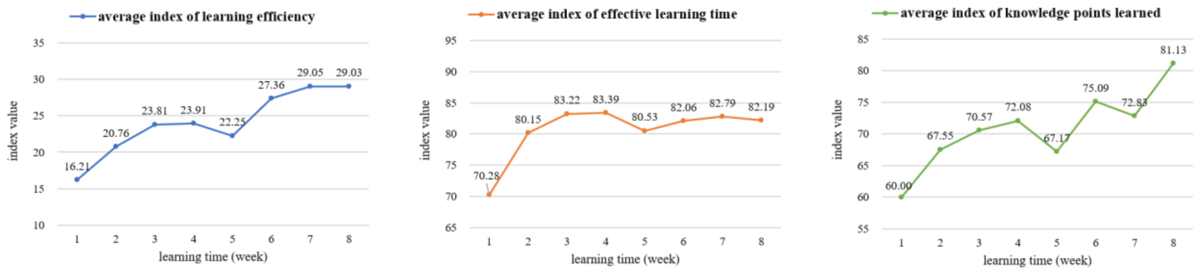
SDL capabilities sub-indicator	Formula
Learning efficiency index(T1)	$T1 = \frac{\min\left[t - time(s), p - time(s)\right]}{p - time(s)} * 100$
Effective learning time index(T2)	$T2 = \frac{a - time(s)}{t - time(s)} * 100$
Knowledge points learned index(K)	$K = \left(\frac{a - knowledge(s)}{p - knowledge(s)}\right) * 100, if(K \geq 1)$， $then\ K = 1$

Figure 7. Variation plot of the average SDL capabilities index in time order



The learning efficiency index continued to increase gradually, indicating that students could gradually manage their learning time effectively within eight weeks, as shown in Figure 8(a). The growth rate of the effective learning time index increased significantly during the first three weeks but had a slower growth rate over time. This may be attributed to the fact that, although varied and novel learning activities could initially spark a high level of willpower and engagement, they did not encourage perseverance. As shown in Figure 8(b), the effective learning time index depending on students' effective engagement fluctuated greatly, and heavy workloads in the fifth week could negatively affect students' engagement. The knowledge points learned index generally showed an upward trend during the experiment, indicating that students became more efficient in achieving self-planned learning goals, as shown in Figure 8(c).

Figure 8. Variation plot of the average SDL capabilities sub-indicator in time order



(a) **Variation plot of the average index of learning efficiency in time order**

(b) **Variation plot of the average index of effective learning time in time order**

(c) **Variation plot of the average index of knowledge points learned in time order**

5.2. Thinking skills

The scores for the students' website design products were used to evaluate thinking skills, applying originality, flexibility, and fluency as three components to confirm the effect of the OSDLE on the final product designs. The principal results of the thinking skills of the control and experimental groups are shown in Table 2.

Table 2. Descriptive statistics for students' thinking skills

Item	Before the experiment				After the experiment			
	Control group		Experimental group		Control group		Experimental group	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Originality	2.77	1.28	2.88	1.52	2.98	1.30	3.64	1.03
Flexibility	2.96	1.28	2.88	1.40	3.11	1.17	3.96	1.05
Fluency	2.94	1.30	3.22	1.50	2.94	1.26	3.56	1.10
Total score	2.89	0.99	3.00	1.06	3.01	0.68	3.72	0.66
p	.594				$.000^{***}$			

Note. $^{***}p < .001$.

Table 2 shows that no significant difference in students' thinking skills was observed between the experimental and the control groups before the experiment ($p = .594$). After the experiment, the results revealed a significant difference in thinking skills between the experimental and control groups ($p < .001$). Moreover, the average gain score of students' thinking skills in the experimental group ($M = 3.72$, $SD = .66$) was significantly greater than that in the control group ($M = 3.01$, $SD = .68$). Therefore, the OSDLE had a beneficial effect in increasing the level of thinking skills.

5.3. Academic achievement

The study also investigated the impacts of the OSDLE on students' academic achievement. Table 3 shows the summary statistics of the t-test. The t-test showed that there was a statistical difference in academic achievement between the experimental group and the control group ($p = .045$) after the learning activities. Additionally, the average gain score of students' academic achievement in the experimental group ($M = 89.03$, $SD = 1.20$) was significantly higher than that in the control group ($M = 85.27$, $SD = 1.41$). The results indicated that students who studied in the OSDLE performed significantly better than those who studied in the traditional classroom environment.

Table 3. Descriptive statistics for students' academic achievement

Group	*N*	*M*	*SD*	*t*	*df*	*p*	*MD*	*SE* difference
Control group	53	85.27	1.41	2.03	104	$.045^{*}$	3.75	1.85
Experimental group	53	89.03	1.20					

Note. $^{*}p < .05$.

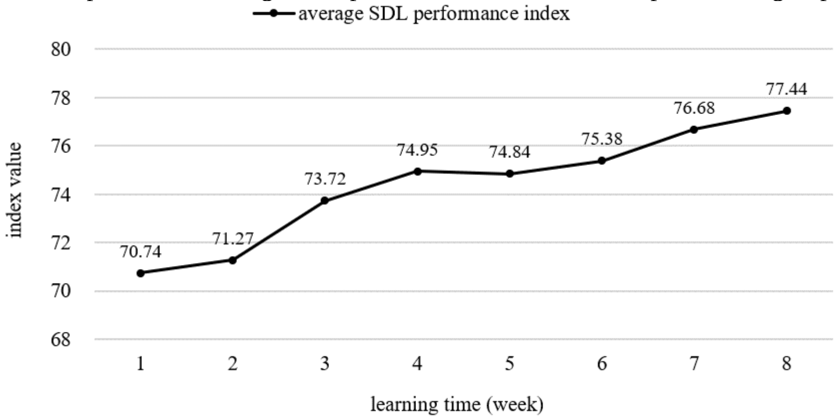
Subsequently, to further analyze the learning process of the experimental group, we calculated their SDL performance index in the OSDLE. The SDL performance index is the mean value of the tests score index (A1) and tasks score index (A2). The formula definition is shown in Table 4, where n is the total number of passed tests, s-test(s)i is the s{th} student's actual test score for the i{th} test, t-testi is the target test score of the i{th} test set by the teacher, s-task(s) is the s{th} student's actual task score, and t-task(s) is the target task score set by the teacher.

Table 4. Formula for SDL performance index

SDL performance sub-indicator	Formula
Average achievement index of tests (A1)	$A1 = \left(\frac{\sum_{i=1}^{n} s - test(s)_i}{\sum_{i=1}^{n} t - test_i}\right) * 100$
Average achievement index of tasks (A2)	$A2 = \frac{s - task(s)}{t - task(s)} * 100$

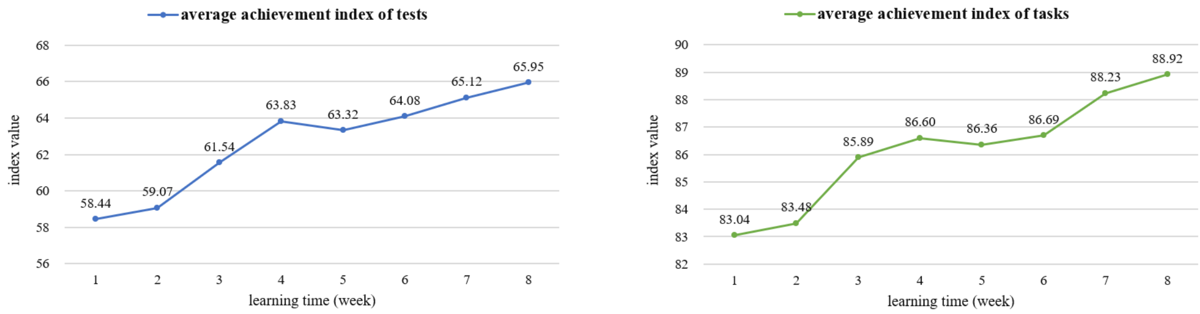
The SDL performance index curve shows that the overall performance of the experimental group indicated an upward trend during the eight-week learning period, as shown in Figure 9. More details of the students' statistical information of SDL performance are shown in Appendix Table 9. A significant difference in SDL performance was observed between the first and eighth tasks ($p = .002 < .05$).

Figure 9. Variation plot of the average SDL performance index of the experimental group in time order



By analyzing the tests score index and tasks score index of 53 students in the experimental group, it can be seen that the increase was particularly noteworthy in the first four weeks, while the students' SDL performance index changed unstably in the fifth week, as shown in Figure 10. The main reason could be that students could skillfully use the OSDLE platform after one week, and their SDL performance was also enhanced. However, during the midterm exam, the learning process was suppressed under the influence of excessive academic burden, which had a negative impact on students' SDL performance. Seven weeks later, the growth rate of SDL performance slowed down, but on the whole, it maintained a slight upward tendency. This may be explained by the fact that students had almost fully adapted to study in the OSDLE, and their performance tended to improve steadily.

Figure 10. Variation plot of the average SDL performance sub-indicator in time order



(a) **Variation plot of the average achievement index of tests in time order**

(b) **Variation plot of the average achievement index of tasks in time order**

6. Discussion and conclusions

To improve students' creativity performance, this study proposed the OSDLE based on the conceptual framework of SDL. This study introduced the OSDLE to a university course to determine whether the OSDLE would positively affect students' creativity performance by analyzing students' SDL capabilities, thinking skills, and academic achievement. The results of the quasi-experiment indicated that the proposed OSDLE significantly improved students' SDL capabilities, thinking skills, and academic achievement. It suggests that using the OSDLE could better support students' creativity performance. The following session discusses the research questions presented at the beginning of the paper.

OSDLE - SDL capabilities (RQ.1). An interesting finding is that the varying curve of SDL capabilities index indicated that the students' SDL capabilities continued to improve gradually in the process of using the OSDLE, and a significant difference could be observed between the first task and the eighth task. Although SDL capabilities have continued to increase in the initial stage, the ascent rate decreased as time. The reason might be that students' SDL capabilities are related to learning motivation. Li et al. (2021) showed a significant relationship between SDL capabilities and learning motivation levels. After the initial enthusiasm, students might feel overwhelmed by various learning activities like the upcoming exams, affecting learning motivation and further impacting SDL capabilities.

With this in mind, future research must consider the maintenance of student learning motivation to improve SDL capabilities. On the one hand, it is necessary to facilitate SDL capabilities-based adaptive feedback systems for students (Jiang et al., 2019), which could enable them to engage more in the planning and monitoring interactions in the OSDLE, and then subsequently affect their learning motivation. On the other hand, the role of self-efficacy in creativity promotion cannot be ignored. Schweder (2019) found that self-effective students tended to be more motivated in learning and thus had higher SDL capabilities. Accordingly, it is recommended that students studying in the OSDLE should be given sufficient guidance and training on goal-setting and monitoring to maintain pleasure during the learning process, which would keep them motivated.

OSDLE - Thinking skills (RQ.2). The findings agree with the positive relationship between the specific learning environment and thinking skills, which is confirmed by the results of Gralewski and Karwowski (2019). OSDLE can significantly improve students' thinking skills statistically. While the course instruction does not emphasize systematic cultivation of thinking skills, OSDLE guides students to make clear and specific learning plans for themselves and drives them to engage in a higher level of task commitment spontaneously. On the whole, OSDLE can exert a significant effect on the development of students' thinking skills.

Seen from the perspective of this paper, OSDLE is related to creativity through its connection to thinking skills. Accordingly, creativity performance can become advanced by developing thinking skills based on the analysis of learning tasks (Rhodes, 1961). Therefore, students' active participation in the course should be encouraged. In this experiment, students participated in the process of creating the website as a creative product. Integrating an appropriate level of knowledge and experience could help students stimulate effective retrieval of knowledge and break the inherent thinking framework for generating original ideas (Ness, 2012), ultimately achieving a high level of thinking skills. This step also facilitates the attainment of creativity performance.

OSDLE - Academic achievement (RQ.3). The experiment results also revealed that the students in OSDLE demonstrated significantly higher academic achievement than those in the traditional classroom. In addition, the SDL performance of students in the experimental group maintained an upward trend. Therefore, the findings indicated the effectiveness of the OSDLE in improving academic achievement. These results are supported by Dunn and Kennedy (2019), whose study investigated the associations between technologies and academic achievement.

Although students are digital natives, individuals are prone to technical pressure because of the failure in timely responding to changes brought by new technologies. Therefore, elaboration prompts are recommended for OSDLE to decrease learning inefficiency caused by system complexity in the future. Before students start learning, it is suggested that a conference on the platform operation should be organized, where the user function can be introduced (Huang et al., 2017). In particular, to promote a creative learning experience, students need to build on their ideas as the first step in developing their creative capacity (Hwang et al., 2021). When students are proficient in using the OSDLE, they can independently participate in learning and interaction through the platform, thereby promoting creativity.

Overall, this study introduced the OSDLE with the functions of planning, learning, evaluation, and reflection into a university course, and examined the effects of the OSDLE on creativity performance. The findings revealed that the OSDLE significantly improved SDL capabilities, thinking skills, and academic achievement. It demonstrated that using the OSDLE could promote students' creativity performance. The main contribution of this study has implications for researchers studying creativity. This study highlighted the contribution of OSDLE to promote creativity performance. OSDLE enables students to develop learning capabilities and thinking skills, enhance academic achievement, and become independent learners to actively generate various original ideas that can foster their creativity in return. Therefore, OSDLE has become one of the valuable environments to support creativity. In addition, this study contributes to the growing body of literature on improving creativity. First, the present study broadened the understanding of the relationship between creativity performance and SDL through pedagogical practice. Second, this study provided the OSDLE to examine the support of educational technology for creativity development in authentic contexts. Finally, some practical implications can be provided for instructors. Specifically, to promote students' creativity performance, proper and sufficient scaffolding should be provided for them, as the OSDLE is a way of planning the learning process by students' choices and pace.

The main limitation of this study is that the research was carried out in a single course. In future work, it would be advisable to implement practices in a greater number of courses from different disciplines, as we did in some of our experiments. Another limitation is that the research mainly focused on the computer-based environment but did not consider a ubiquitous learning environment. Further studies are needed to apply the results to mobile learning to increase the practical value of this research.

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Appendix

Figure 11. An example of two-tier multiple-choice items for tests

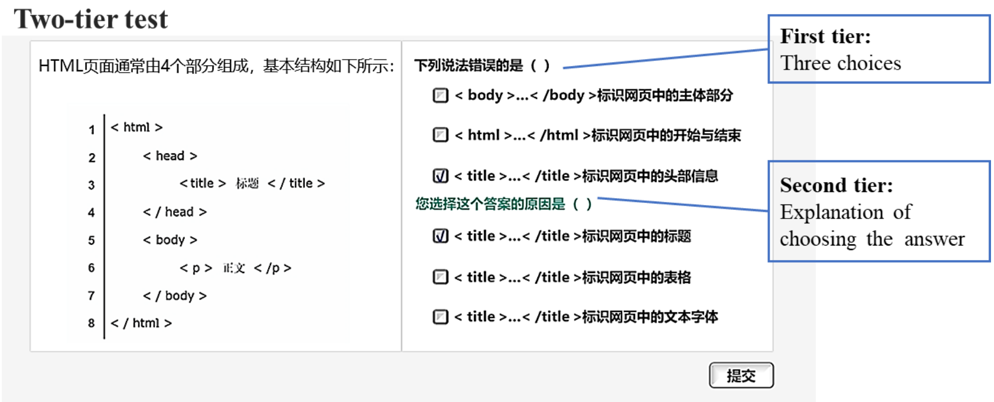

Table 5. Illustrative example of a two-tier test item

Question: In the following example, the basic structure of an HTML5 document consists of 4 elements: 1.<html> 2.<head> 3.<title> TITLE</title> 4.</head> 5.<body> 6. CONTENT 7.</body> 8.</html> Which of the following statements is incorrect for this basic structure?	
First tier	Second tier
a. <body> … </body> represents the content of an HTML document	(a1) The <body> element defines the document’s body. (a2) The <body> element represents introductory content. (a3) The <body> element contains meta information about an HTML page.
b. <html>…</html> delimits the beginning and the end of an HTML document	(b1) The <html> element is the root element of an HTML page. (b2) The <html> element defines that this document is an HTML5 document. (b3) The <html> element defines a paragraph.
c. <title>…</title> defines the head of an HTML document	(c1) The <title> element defines a large heading of an HTML page. (c2) The <title> element defines a chat heading. (c3) The <title> element defines the document’s title that is shown in a browser’s title bar or a page’s tab.

Table 6. Task rubric

Criteria	(Strongest) 5	4	3	2	(Weakest) 1	Percentage
Completeness & Accuracy	The product is complete and correct.	The product is complete, but there are still some	The product is almost complete, but half of the	The product is somehow complete, but most of the	The product is not complete or unrelated.	40%

		mistakes in the content.	details are wrong.	details are wrong.		
Layout	The product has an exceptionally attractive and easily navigable layout.	The product has an attractive and usable layout.	The product has a usable layout, but some parts may appear busy or boring.	The product has a cluttered or confusing layout.	The product has an unusable and disorganized layout.	20%
Design	The project has five of the following: • Captures attention • Visually interesting • Engaging • Well crafted • Has an aesthetic quality	The project has four of the following: • Captures attention • Visually interesting • Engaging • Well crafted • Has an aesthetic quality	The project has three of the following: • Captures attention • Visually interesting • Engaging • Well crafted • Has an aesthetic quality	The project has two of the following: • Captures attention • Visually interesting • Engaging • Well crafted • Has an aesthetic quality	The project has zero or one of the following: • Captures attention • Visually interesting • Engaging • Well crafted • Has an aesthetic quality	20%
Creativity	Was extremely clever and presented with originality. A unique approach that truly enhanced the product.	Thoughtfully and uniquely presented. Was clever at times.	Added some original touches to enhance the product, but did not incorporate them throughout.	Have only a few unique aspects. Most elements are copied from the sample.	Unoriginal or borrowed product.	20%

Table 7. The Creative Product Scale

Please use your subjective opinion of three dimensions of creativity to evaluate each creative product individually. The description provided is only a suggestion to guide your evaluation.

1. Originality: Refers to the percentage of pages that differed from the categories covered by the reference sample.
1- Generates repeated ideas.
2- Generates a few unique or unusual ideas.
3- Generates several unique or unusual ideas.
4- Generates a sufficient volume of unique or unusual ideas.
5- Takes a novel, unique or unusual approach to idea generation.

2. Flexibility: Refers to an estimate of the degree of website layout friendliness.
1- Presents ideas in isolation.
2- Simple connections are made between a part of ideas.
3- Reasonable connections are made between ideas.
4- Often makes effective connections between ideas using various organizational techniques.
5- Makes precise and complex connections between different related ideas in unexpected ways.

3. Fluency: Refers to an estimate of how many types of functions were designed.
1- Shows an inability to design any functions creatively.
2- Presents functions that are vague or incomplete and are not considered to be unique.
3- Presents a few functions that are considered to be somewhat valuable and unique.
4- Presents sufficient functions to be considered valuable and unique.
5- Shows an impressive level of creative, diverse functional design.

Table 8. The students' statistical information of eight weeks based on the average learning efficiency index, the average effective learning time index, the average knowledge points learned index, and the average SDL capabilities index

Learning time (week)	Number of students	Learning efficiency index		Effective learning time index		Knowledge points learned index		SDL capabilities index	
		Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
1	53	16.21	2.45	70.28	3.59	60.00	3.23	48.83	1.89
2	53	20.76	3.29	80.15	3.73	67.55	3.62	56.15	1.89
3	53	23.81	3.75	83.22	2.90	70.57	3.71	59.20	2.05
4	53	23.91	4.13	83.39	3.63	72.08	4.15	59.79	2.60
5	53	22.25	3.68	80.53	3.34	67.17	3.00	56.65	1.79
6	53	27.36	4.14	82.06	3.21	75.09	3.84	61.50	2.49
7	53	29.05	4.07	82.79	3.45	72.83	3.57	61.56	2.42
8	53	29.03	3.97	82.19	2.91	81.13	2.71	64.11	1.89

Table 9. The students' statistical information of eight weeks based on the average achievement index of tests, the average achievement index of tasks, and the average SDL performance index

Learning time (week)	Number of students	Achievement index of tests		Achievement index of tasks		SDL performance index	
		Mean	*SD*	Mean	*SD*	Mean	*SD*
1	53	58.44	2.29	83.04	1.76	70.74	1.45
2	53	59.07	3.07	83.48	2.11	71.27	1.91
3	53	61.54	2.963	85.89	1.94	73.72	1.75
4	53	63.83	3.02	86.60	1.88	74.95	1.73
5	53	63.32	3.46	86.36	1.76	74.84	1.63
6	53	64.08	3.33	86.69	2.29	75.38	2.05
7	53	65.12	3.25	88.23	1.67	76.68	1.99
8	53	65.95	2.58	88.92	1.26	77.44	1.26