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The Impact of Productive Failure on Learning Performance and Cognitive Load: Using Hypervideo to Facilitate Online Interactions

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Abstract*—Videos are being used increasingly to deliver subject knowledge in online learning, but their use has long been criticsed for a lack of learner-to-learner interaction, which can result in high dropout rates. This highlights the need to reconsider instructional approaches and the design of online enviornments. Productive failure is an instructional approach that uses students' cognitive conflicts to enhance their learning, usually in a "practice-teach" sequence. The present experimental study investigated the effect of productive failure in a hypervideo environment which provided timeline comments for learners to navigate different part of videos. Forty-one students particiaped the experiment, randomly assighed into the experimental group - productive failure and the control group - direct instructional . A post-test and cognitive load scale was used to assess the performance of students. It was found that, compared to direct instructional methods, productive failure strategies significantly improved learner performance, reducing intrinsic cognitive load. The study contributes to the design of hypervideos to facilitate learner-to-learner interactons, while preventing learners from becoming overloaded.

***Keywords*—Productive Failure, Hypervideo, Cognitive load**

I. Introduction

Although Massive Open Online Courses (MOOCs) offerings are increasing, the alarmingly high dropout rates (greater than 90%) serve as a critique of its deficient quality [1]. As MOOCs are known as the open products of elite universities, the criticism of their quality has not been focused only on content knowledge, but has also been turned to the design, which lacks tutor-learner and learner-learner interactions.

Recently years, hypervideos were introduced to enhance learner-to-learner interactions in open and flexible learning environments, but learners lacked regulation and it was not feasible for teachers' interactions to meet the diverse demands of learners. Hypervideo is a form of hypermedia that creates a nonlinear structure for streamlining videos [2]. In hypervideo learning environments, hyperlinks (timeline comments) allow learners to view videos in different orders, and to interact with others via comments. The comments that are associated with timestamps in videos creates a "pseudo-synchronic," co-viewing experience" [3].

Productive failures, often used as an effective instructional strategy, have been shown to be effective in facilitating learners to reconcile what they need to learn. Therefore, this study used productive failure strategies as teachers' initiatives to activate learners' prior knowledge, and further improve their engagement in timeline-anchored discussions. Self-developed hypervideo platforms were used to improve learner-to-learner interactions while learners made their own efforts to learn. Newly added features might be conductive to learning, but inevitably increase cognitive load, thus this study attempted to explore whether productive failures and hypervidoe facilitate better online learning, without increasing cognitive loads.

II. Review of Literature

A. *Productive Failure Theory*

Kapur [4] proposed the productive failure theory, which suggests that experiencing some failure in the early stages of problem solving helps students to learn more effectively. Kapur divided the process (or experience) of productive failure into two stages. In the first stage, the teacher presents a difficult problem or project for students to solve, by working in small groups with little or no scaffolding. This phase encourages diverse ways of thinking and reconciliation. Even though the learners might experience some sense of failure in the process of searching for a solution, this does not necessarily cause frustration, but rather generates "representations and solutions"(RSMs) in the process. Kapur [5] referred to this phase as the "exploratory-generative" learning stage. After a strong sense of "failure", students have a deeper sense of the problem, so that when they receive the answer to the problem at this stage, they have a deeper understanding of the concept and a better level of transfer, which results in effective learning, a process known as the "integration-consolidation" stage.

According to Loibl and Rummel [6], productive failure theory is most effective for problem-solving learning [2] and has been shown to be particularly applicable in mathematics and science courses [5]. The experiment considers the effects of effective failure and direct instructional instruction on students' online hypervideo learning.

B. *Cognitive Load during Online Learning*

Research has shown that a hypertext online learning environment can create additional cognitive demands on learners [7], which can be expressed in terms of cognitive load. This additional cognitive process may act as a source of extraneous load in limited working memory resources, resulting in learners only acquiring fragments of knowledge rather than being able to construct a coherent knowledge structure [8].

Cognitive load theory is a framework that provides theoretical guidance for studying cognitive processes and instructional design [9], Cognitive load refers to the total amount of cognitive resources required by a person to process information during the completion of a task. Sweller [10] defined cognitive load broadly as the multidimensional structure of individual cognition used to process a task, learn, or solve a problem. There are three types of cognitive load [11]: intrinsic

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cognitive load (ICL), extraneous cognitive load (ECL) and germane cognitive load (GCL). The load formed by the interaction between elements is called internal cognitive load (ICL), which depends on the interaction between the nature of the material to be learned and the expertise of the learner and on which the instructional designer cannot have a direct influence; external cognitive load (ECL) is additional load beyond the internal cognitive load, which is mainly caused by poorly designed instruction. germane cognitive load (GCL)is the load associated with facilitating the process of schema construction and schema automation. In terms of the process of constructing new knowledge, students who have experienced "failure" may be more aware of what they want to learn, and the hypervideo, with its non-linear and flexible access format, can better support their adaptive learning. Therefore, productive failure instruction may be an effective teaching approach for improving interactions in hypervideo learning.

III. Research Qusetion

Aiming to support learner-to-learner interactions better in open and flexible learning environment, this study used hypervidoes to test productive failure theories, attempting to seek answer to the research question: Does the use of productive failure in hypervideos increase learning performance, and increase cognitive load?

IV. Method

A. Participants

54 Participants were recruited from an undergraduate elective course "Big Data in Education" at a university in Beijing. The participants were either sophomores, juniors, or seniors, in different educational backgrounds, (see Table 1). The subjects had a basic knowledge of mathematics and statistics at the high school level. Their participantion was voluntary, and they could withdraw at any time. Due to incomplete questionnaire data, duplicate submissions, and dropouts, a total of 41 participanets took part, 22 in the experimental group and 19 in the control group.

TABLE I. Demographic characteristics of effective participants in terms of gender, professional background

	Group PF	Group DI
Gender		
Male	15 (68.9%)	11 (57.9%)
Female	7 (31.8%)	8 (42.1%)
Sum	22	19
Academic Background		
Mathematics, Statistics, Finance	7 (31.8%)	4 (21.05%)
Management	4 (18.2%)	4 (21.05%)
Physics, Astronomy	4 (18.2%)	3 (15.79%)
Pedagogy, Psychology	3 (13.6%)	4 (21.05%)
Computer Science and Technology	2 (9.1%)	2 (10.53%)
Biological, Geographical	2 (9.1%)	2 (10.53%)
Sum	22	19

B. Platform

The hypervideo learning platform was developed to allow learners to post or reply to video-tagged comments, which offers hyperlinks for other learners to identify the parts of videos watched along the timeline. It was specially developed for this experiment, using JAVA and PHP. The hypervideo platform was divided into four main areas: A, B, C, and D. Area C contained hyperlinks that were linked with timeline comments in Area D. Either clicking on coloured dots in Area C or timeline comments in Area D navigated learners to the timestamp when other learners left comments.

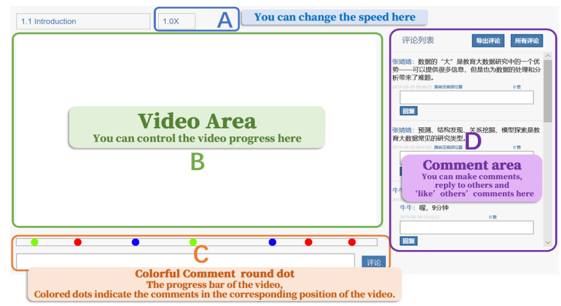

Fig. 1. The Interface of Hypervideo Platform

C. Materials

1) Video

The MOOC "Big data in education" designed by Ryan Baker, a professor at the University of Pennsylvania, USA, was selected as the experimental material after obtaining his consent. The first three videos of the first week, that is 1.1 Introduction, 1.2 Prediction, and 1.3 Classification Part 1, were used in the experiments. Each video was approximately 10 minutes in length. The videos were provided with Chinese subtitles.

2) Pre-test

The pre-test contained four questions (2 single-choice, 2 fill-in-the-blank), which were used in Baker's real MOOC course to test the prior knowledge of participants before taking part in the experiment.

3) Post-test

The posttest contained two parts: **a)** four questions used in the pre-test to test knowledge gained during the experimentation; and **b)** cognitive scales including 22 questions in total, divided into two parts) measuring the cognitive load of the experimental participants while completing various learning activities (including watching instructional videos and completing challenge tasks). Cognitive load scale was adapted from existing studies of Krell [12], and a good reliability obtained (ICL-α= 0.86, ECL-α = 0.80, GCL-α = 0.80. The cognitive scales were used after learning through the hypervideo.

D. Experimental Conditions

The independent variables of this experiment were the instructional approach, informed by the Productive failure theory. Experiment process can be seen in Fig 2. A two-group comparison design was adopted.

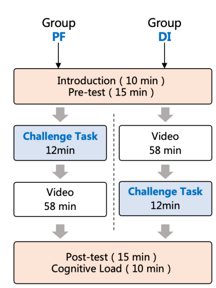

Fig. 2. The Process of the hypervideo experiment.

a) Productive Failure: In this study, the learners in the experimental group were required to complete a challenge task before proceeding to watch hypervideos. In this study, the challenge task was set and adapted from Baker et al. [13].The challenge task required the learners to use a data mingling approach to solve an educational problem with psedu datasets.

b) Direct Instructional: The teacher first gave instruction about the subject knowledge, and the learners received direct instruction before completing the learning tasks. The teaching sequence instruction isfollowed by the learning task. In this study, the learners in the control group first watched the instructional video, before they completed the challenge task.

V. Result

Student's performance was assessed using tests and challenge tasks. An independent sample t-test of the challenge task of the PF and DI groups showed no significant difference between the two groups, but the mean score of the challenge task in the PF group (M = 3.36) was slightly lower than that in the DI group (M = 3.77).

The independent sample t-test showed that there was no significant difference between the PF and DI groups on the pre-test and no significant difference on the post-test. Nevertheless, a paired sample t-test showed that there was a significant difference between the pre- and post-tests for the PF group, and the post-tests were significantly higher than the pre-test scores (see Table II). There was no significant difference between the pre- and post-test scores of the DI group.

TABLE II. Differences in pre and post test scores between the productive failure group and the direct instruction group

Group	*N*	*Pre-Test*	*Post-Test*	*t*	*Sig*
PF	22	3.41	3.77	-2.592	**0.017**[a]
DI	19	3.37	3.58	-1.455	0.163

a. p is significant at the level of 0.05

As shown in Table III, no significant differences were found in the extrinsic and germane load for video learning. Nevertheless,the intrinsic cognitive load was significantly lower in the PF group than in the DI group, that is, the productive failure approach did not increase the intrinsic load for the learners.

TABLE III. Differences in pre and post test scores between the productive failure group and the direct instruction group

	Group	*N*	*M±SD*	*Standard error value*	*t*	*Sig*
ICL	PF	22	4.417±1.358	0.538	-0.794	**0.048**[b]
	DI	19	4.844±0.719			
ECL	PF	22	3.673±1.124	0.371	-1.11	0.274
	DI	19	4.084±1.250			
GCL	PF	22	4.065±0.706	0.252	0.497	0.622
	DI	19	3.940±0.904			

b. p is significant at the level of 0.05

VI. Discussion

In this study, a two-group experiment was conducted to test whether productive failures and hypervidoes facilitated better online learning, without increasing cognitive loads.

a) Learners using direct instruction completed the challenge task better than those using productive failure. As the learners took the challenge task first before watching the video, the results further confirmed that those in the experimental group did experience some difficulties when working on this task, which is consistent with Kapur's [4] study. Although the learners using productive failure to teach did not perform well on the challenge task, they showed a significant increase in the subsequent post-test, demonstrating that such failure is also “productive” and "effective" in online enviorments.

b) In terms of intrinsic cognitive load, the learners using productive failure seemed to perceive less intrinsic load, which may be related to the fact that the challenge task helped them to activate their prior knowledge while being the first to complete the task, and thus they felt relatively less psychologically taxed when watching and interacting with the videos.

Based on the above findings, the study results suggest that productive failure strategies are promising instructional strategies to be applied in online learning courses, which might help learners to identify their learning goals and be more proactive in video learning. The flexible and non-linear structures created by the hypervideo also showed that it further increased the learners’ performances in such a short period of time.

The limitation of this study is noted. Due to the capacity of the face-to-face course conducted at the university in Beijing, it was not possible to recruite participants other than the registered learners. The learners who seleted this course were interested in big data in education, thus minimizingx the effect of motivation and intentions that could have been added by recuiting participants more widely. The sample size of the present study was modest, which may have had an impact on the test of variability of the experimental results.

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