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Improving Primary Students' Problem Solving Skills in Science Learning in a Seamless Learning Environment

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Abstract: The paper reports on an empirical study aiming at improving students' problem solving skills in science learning on "Plant Adaptations" in a seamless learning environment in a primary school. Two Grade 6 classes with 28 and 26 students respectively participated in this study. One class (G1) adopted project-based learning approach using a productive failure (PF) instructional design; the other class (G2) adopted project-based learning approach without using (PF) design. In G1, the students explored ways to grow plants in different conditions on their own without learning the related concepts and facilitated by the teacher about the misconceptions and assembly of conceptual knowledge after students' completed their project; in G2, the students learned the related concepts first, then did the project. The learning activities spanned spaces across home, farm and school supported by mobile devices. Data collection includes pre- and post-domain tests, pre- and post-questionnaire on self-reported problem-solving skills, and student interviews. Both quantitative and qualitative methods were employed in the data analysis. The research findings show that compared to G2, the students in G1 improved domain knowledge after the project, and male students became more confident and critical in solving problems than female students, but female students developed better personal control than male students.

Keywords: Science learning, problem solving, conceptual understanding, productive failure, seamless learning

1. Introduction

In the digital age, problem solving is one of the 21st Century skills that we believe critical for preparing students in a global economy and society with increasing diversity, rapid change and efficient communication (Voogt & Roblin, 2012). Cultivating students' problem solving skills means to engage students in solving a problem using different strategies, from multiple perspectives and with diverse modalities. This is in line with what is advocated in science education in Hong Kong that comprises a core component of the primary school General Studies' curriculum. Doing science is to use the methods and procedures of science to investigate a phenomenon, test and develop understanding, solve problems and follow interests (Hodson, 2014). It promotes creativity through problem-solving process in authentic learning environments supported by digital technologies (The Education Bureau, 2011). However, in practice, science learning, in many cases, is still largely disconnected from learners' daily life and confined to textbook learning (Anastopoulou et al. 2012). Students are passive knowledge receivers resulted from a lack of opportunities to be question askers, inquiry method designers and action-takers. How to develop students' problem solving skills adopting innovative instructional design in a seamless learning environment is the main concern of this proposed project.

2. Literature

2.1 Productive Failure-based Instructional Design

Productive failure is defined as "a learning design that affords students opportunities to generate solutions to a novel problem that targets a concept they have not learned yet, followed by consolidation and knowledge assembly where they learn the targeted concept" (Kapur, 2015, p. 52). Productive failure instructional design first engages students in unguided problem solving to elicit their prior knowledge, particularly in the failure to solve the problem, followed by using this information to consolidate and aggregate new knowledge (Kapur, 2016). The failure stems from the fact that learners are commonly unable to generate or discover the correct solution to the novel problem by themselves; on the other hand, they are able to generate sub-optimal or even incorrect solutions to the problem, the process can be productive in preparing them to learn better from the subsequent instruction that follows (Kapur, 2014). Indeed, in science learning, generating "wrong answers" may help to focus students' attention on the complexities and frustrations of a good investigation plan or design (Hodson, 2014).

2.2 Project-based Learning in a Seamless Learning Environment

Project-based learning is premised on constructivism and experiential learning and situated learning theories (Hmelo-Silver, Duncan , & Chinn, 2007; Kolb, A. Y., Kolb, D. A., Passarelli, & Sharma, 2014). In science learning, this approach aims to involve students in working at real-world problems in small groups and striving for solution options where the teacher acts as a facilitator (Brundiers & Wiek, 2013). The research literature shows that project-based learning can help students enhance learning performance in knowledge advancement and skill development, and motivate them to learn (Mioduser & Betzer, 2013). To achieve better learning outcomes, it is suggested taking into account the factors such as the complexity of the project, level of the learners, the learners' prior knowledge and appropriate support (Thomas, 2000). In the digital age, learning becomes ubiquitous and seamless. Seamless learning refers to learning supported by mobile technologies across difference learning spaces in reconstructed contexts such as physical and virtual, formal and informal and individual and social spaces (Wong & Looi, 2011). However, how to develop students' problem solving skills in a seamless learning environment still needs to be explored.

Thus this study addressed two research questions: (1) Was project-based learning using productive failure instructional design effective in developing students' problem solving skills in a seamless learning environment? (2) Did students advance their science knowledge after this project based learning in a seamless learning environment?

3. Methods

3.1 Research Design

This study was conducted in two Grade 6 classes (G1 and G2) with 28 and 26 students respectively on "Plant Adaptations" in a seamless learning environment in a primary school. There are four groups of students in each class. Each group had an iPad borrowed from the school. G1 adopted project-based learning approach using a "productive failure (PF)" instructional design; G2 adopted project-based learning approach without using (PF) design. In G1, the students explored ways to grow plants in different conditions on their own without learning the related concepts and facilitated by the teacher about the misconceptions and assembly of conceptual knowledge after students' completed their project; in G2, the students learned the related concepts first, then did the project. Both G1 and G2 students investigated the problems related to plants and their environments in different spaces across home, farm, school and online supported by mobile devices in groups. The study lasted for two weeks.

The objectives of the project "Plant Adaptations" for both G1 and G2 are to choose two kinds of Rhizome plants to grow, and find out factors that influence the growth of the plants they choose. By doing so, students needed to work in groups to make their own plans to raise the plants. In order to understand better the factors that contribute to the growth of the plant, they usually prepared two or three plants of the same kind to raise in different conditions (e.g., different intensity of light, and amount water), observe, document and explain their process of growth.

3.2 Data Collection and Analysis

Data collection includes student pre- and post-domain tests, pre- and post-questionnaire on self-reported problem-solving skills, and student interviews. Pre- and post-domain tests had 8 multiple choice questions related to factors related to plant growth. The questionnaire was constructed based on the validated "Personal Problem-Solving Inventory" (Heppner & Petersen, 1982) in 3 dimensions: problem-solving confidence, approach avoidance style and personal control. It consisted of 23 questions on a 5-point Likert scale from 1 (never or rarely) to 5 (always). We received the valid responses from all the students in G 1 (25 students) and G2 (26 students). The focus group interview had 5 questions. Two groups of students with 3-4 students in G1 and G2 respectively participated in the interview. The interview lasted about 35 minutes for each group.

Both qualitative and quantitative methods were employed in the data analysis. Students' domain knowledge scores were rated according to the number of items that they selected answers indicating a traditional mindset on this domain knowledge. In total, the highest score is 8. Students' problem solving scores were rated with a range from 1 to 5, on three sub-dimensions including problem solving confidence, approach avoidance orientation (negative rated), and personal control skills. Students' focus group interviews were analysed using content analysis to do coding under the framework of the three dimensions of the questionnaire.

4. Research Results and Discussions

4.1 Pre- and Post-Domain Tests

First, students' mean scores in the pre-domain test and the post-domain test were calculated in two ways: first they were calculated according gender; secondly they were calculated according to groups of G1 and G2. The results are shown in Table 1. ANOVA analysis results showed gender differences were insignificant in both pre-domain and post-domain mean test scores ($F=0.017(1,52)$, $p>0.05$; $F=1.135(1,52)$, $p>0.05$); group differences were significant in pre-domain mean test, while was insignificant in the post-domain test mean score ($F=6.468(1,52)$, $p<0.05$; $F=0.023(1,52)$, $p>0.05$). These results indicated that there was a difference in students' domain knowledge of these two groups at the beginning of the course with G2 performed better than G1. However, the difference was diminished at the end of the project. This indicates that G1 improved their learning after the project.

Secondly, paired T-test analysis of students' domain test scores on these two tests achieved the following results: there was significant difference in students' pre-domain test scores and post-domain test scores in G1 ($t(27)=2.777$, $p<0.01$), but not in G2 ($t(25)=0.000$, $p>0.05$). In addition, there was significant difference in female students' pre-domain test scores and post-domain test scores ($t(28)=2.736$, $p<0.05$), but not male students ($t(24)=1.000$, $p>0.05$). The results indicate that in G1, students' traditional mindset on the domain's knowledge transformed significantly after the project, and females benefited more than males. By triangulating participants' statements about reasons of transformation, it can be concluded that the project helped them to build up scientific domain knowledge.

Table 1: A comparison of pre-domain and post-domain test scores

		Pre-test	Post-test		
	N	Mean	SD	Mean	SD
Gender:					
Female	29	3.68	1.228	3.03	1.149
Male	25	3.64	1.578	3.44	1.635
Group:					
1	28	3.19	1.327	3.19	1.575
2	26	4.11	1.315	3.25	1.236
Total	54	3.67	1.39	3.22	1.40

4.2 Students' Problem Solving Skills

Students' mean scores of problem solving skills measured before and after the course were calculated, and shown in Table 2. Paired T-test about the difference between G1 and G2 were conducted. The results of this analysis show that no significant differences in G1 and G2 were found in students' problem solving skills on all three dimensions of problem-solving confidence, approach avoidance style and personal control before and after the project. However, there was a significant increase in students' problem solving confidence of the male group, but not the female group ($p<0.01$). The results indicate that male students benefit more than female in their problem solving confidence by doing the project using productive failure instructional design. In addition, a close to significant decrease in male students' personal control during problem solving was also found ($p=0.058$) in the two groups. The results indicate that the course may be able to raise more personal control challenges for the male students.

Table 2: Scores of students' problem solving skills achieved before and after the course

	Confidence				Approach avoidance				Personal control			
	Before		After		Before		After		Before		After	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group:												
Group1	3.02	0.541	3.09	0.607	3.19	0.531	3.20	0.620	3.79	0.873	3.54	0.810
Group2	3.12	0.617	3.23	0.555	3.19	0.584	2.99	0.634	3.62	0.921	3.58	0.956
Gender:												
Female	3.00	0.700	2.96	0.676	3.34	0.516	3.27	0.579	3.74	0.865	3.76	0.840
Male	3.19	0.426	3.36**	0.566	2.96	0.434	2.89	0.645	3.61	0.949	3.32	0.885
Total:	3.10	0.558	3.156	0.581	3.16	0.505	3.10	0.630	3.59	0.883	3.56	0.875

We interviewed 2 groups with 3-4 members in G1 and G2 respectively. We categorize the themes in three problem solving dimensions of problem-solving confidence, approach avoidance style and personal control. The results show different views of students in the project-based learning supported by mobile technologies in G1 and G2. For example, regarding problem-solving confidence, when asked how they knew that the plant's growth is relevant to the intensity of light, the students in G1 reported that they learned it by their own observation, capturing the photos, and making comparison and contrast with those growing indoors. Their new findings were: the leaves of the plants growing outdoors usually spread around; but the leaves of the plants growing indoors unusually went upwards for light; while students in G2 grew bean sprouts and found that the growth of green beans growing in water and soil was different. When asked what the differences lay, they said they did not know and did not have the intension to find it out later.

In terms of approach avoidance style, when asked how they made their plan to grow the plant in different conditions, the students in G1 reported that they searched information on their own, and discussed in groups via WhatsApp and face-to-face. Finally, they worked out a plan of growing the plant; while students in G2 responded that their teacher provided guidance for the plant growth (e.g., Don't put too much water.).

Finally, regarding personal control, when asked whether they felt frustrated and grew a sense of failure in failing to grow the plant, the students in G1 responded that instead of having a sense of failure, they had a sense of success as they successfully grew other kinds of plants and learned more about the conditions or environments for specific kind of plants' growth, and were glad to know more about the functions of plants; while students in G2 reported that they felt a bit disappointed about failing in growing the plant, but did not mention what they thought of the plants that they raised successfully.

Thus, from the examples we noted that the students in G1 were engaged in active learning by exploring and finding out solutions on their own without fearing of failures. The results were in line with the findings of studies using productive failure instructional design in mathematics learning (Kapur, 2014). However, students in G2 needed guidance during their inquiry and did not form the habit of challenging the problems they could not understand. Mobile devices supported the students in documenting the growth of the plants they studied.

5. Conclusion

The paper reports on an empirical study to examine the effectiveness of G1 of the project-based learning using productive failure instructional design on students' science learning and problem solving skills development in a seamless learning environment in a primary school compared with G2 without the instructional design. The research findings show that compared to G2, the students in G1 improved domain knowledge after the project, and male students became more confident and critical in solving problems than female students, but female students developed better personal control than male students. Mobile technology helped their project-based learning in documenting the growth of the plants with camera or recording functions, and communicating with group members. Future research needs to be done to examine the effectiveness of the productive failure instructional design in a seamless learning environment in schools at a larger scale.

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