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Inspiring Future Hydraulic Engineers with Problem-Based Learning

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I. Abstract

In Taiwan, the importance of the hydraulic engineering field is growing, particularly in terms of recent water supply sustainability issues and the ongoing prevalence of weather-related events and challenges, such as droughts and floods. In order to inspire 21st century students who will serve as professionals in the hydraulic engineering field, problem solving abilities must be emphasized, fostering flexibility and innovative as well as effectiveness, which are necessary for an uncertain and unpredictable future. This study applies project-based learning (PBL) to hydraulic engineering education. PBL were designed for an undergraduate course to emphasize real-world problems while enhancing learning motivation and performance, and fostering the problem-solving skills necessary for innovation and excellence in the learners' future professional careers as hydraulic engineers. Not only divergent thinking activities, but also convergent thinking strategies (i.e., those which involve evaluating and selecting among generated innovative thoughts according to the guidelines and purposes of the activity) were adopted to better guide students in generating both innovative and effective solutions to real-world hydraulic engineering problems. The study adopted a pretest and posttest quasi-experimental design. Over an 18-week intervention, students in the experimental group completed the above-mentioned intervention, while comparison group worked on projects that did not integrate problem solving activities. Participants' final reports, which proposed solutions to the real-world issues, such as reservoir sedimentation, were evaluated and scored by an expert panel, including representatives from academic, governmental, and industrial backgrounds. A statistically significant advantage was found for students in the experimental group in terms of academic achievement on the post-test, as well as significantly greater improvement in problem-solving and professional skills. This study explored how different teaching strategies influence students' problem-solving skills and, at the same time, hydraulic engineering knowledge.

II. Introduction

The new millennium has brought several challenges to engineering education, which must be considered if we are to provide an adequate foundation for learners who will ultimately join the engineering field as future professionals, whether in industry, academia, or in policy-making positions. As such, it is necessary to consider the importance of professional abilities, as well as higher order thinking skills, which will empower future professionals in solving uncertain and ever-changing challenges which will face them as they embark on their careers. For hydraulic engineers such challenges involve the need for real-world problem-solving of problems facing them due to extreme weather and water supply sustainability issues. Additionally, innovation and creative thinking is essential for both identifying, solving, and avoiding problems in the future.

Taiwan is in a zone which often experiences extreme weather, such as typhoons and tropical storms which can bring a large amount of rainfall in a short period of time. The management of water resources and infrastructure is an ongoing and critical issue in the field, particularly as recent years have experienced water storage in reservoirs and a resulting rationing of water in certain locations due to a reliance upon the national reservoir system. Among those reservoirs which are actively used, the problem of excessive sediment deposits is becoming an increasingly critical focus for engineers [1], since these sediments reduce reservoir capacity, negatively impact reservoir functions, and may even pose safety hazards [2].

Globally, it is estimated that net reservoir storage has dramatically reduce due the fact that the rate of sedimentation (which has be estimated at 0.53% per year) exceeds the pace of new storage construction [3], [4]. In Taiwan, about 90% of the annual rainfall occurs during wet season, from May through October, with only 10% of rainfall occurring during the rest of the year. This pattern of precipitation places demands on both water supply consumption as well as facilitating the development of sediments, placing Taiwan's reservoirs in a hazardous situation. For example, in August 2009, typhoon Morakot caused reservoir sedimentation in excess of about 90 million m^3 over a single event. In response to the extreme sedimentation caused by this single event, several expensive projects were required, including reactive solutions, such as hydrosuction or mechanical removal of sedimentation, and proactive approaches, including the construction of upstream check dams and the development of hillside erosion control techniques. Since these measures yield limited results, hydraulic engineers in Taiwan continue to assess current options and seek alternative innovations to improve sediment management.

As mentioned above, population growth, economic development, and the occurrence of extreme weather has resulted in water-related problems which have complicated and thus threatened the quality of human life and the environment. With increasing demands placed upon water storage infrastructure and a dwindling number of practical and economically suitable locations available for reservoir development, the loss of capacity in existing reservoirs threatens the future sustainability of the water supply [3]. While some dams can be designed or retrofitted to pass sediment through various techniques, each viable solution itself requires adopting an additional set of constraints or conditions. As such, techniques for sediment management are not adopted widely, even in reservoirs which could benefit from desiltation. This is one challenge facing the future of hydraulic engineering in Taiwan, since some current practitioners may be unaware of the growing range of validated sediment management approaches, highlighting the importance of hydraulic engineering education in providing practical and relevant learning for managing the consequences of reservoir sedimentation while also fostering higher order thinking skills, such as creativity and problem solving.

Therefore, it is critical that hydraulic engineering education confronts students with these real-world issues and prepares them with the background and training which will foster the professional and critical faculties necessary to meet the demands of the hydraulic engineering field in the future.

While traditional engineering education has focused on first providing a solid background in mathematics and engineering principles, PBL, which involves students actively solving theoretical or practical problems over an extended period of time using their knowledge of the domain, has become the dominant pedagogy for engineering education in recent years [12]. From the perspective of hydraulic engineering, Johnson [13], states that lecture-based instruction cannot improve creativity or problem-solving and is often unable to prepare students for problems they will face as professionals. As such, PBL has increasingly been utilized by engineering educators. The U.S. National Science Education Standards [14] recommends a type of inquiry-based learning to encouraging student in explore and creating their own scientific knowledge.

In terms of PBL for hydraulic engineering students, our previous work [17] showed some positive impacts on students' professional skills, but did not impact innovative problem-solving as positively as expected. Thus, we have reconsidered the former approach, which largely adopted divergent thinking techniques for fostering innovation within a PBL scenario. In order to promote the type of thinking which can lead to practical, real-world solutions to hydraulic engineering problems, it is deemed necessary to adopt convergent thinking activities which will allow for a greater focus, evaluating potential solutions according to a framework which emphasizes feasibility, effectiveness, and relevance to the issue being explored.

In this study, we evaluate the effects of divergent and convergent thinking skills in a hydraulic engineering PBL context, evaluating the learning outcomes of academic achievement, professional abilities, creativity, and problem-solving, as well as communication skills.

III. Methods

A. Research Design

This study adopted a pre-test post-test quasi-experimental design to evaluate the proposed creativity-integrated PBL intervention. The independent variable was instructional strategy, with two levels: Creativity-integrated PBL was adopted for the experimental group (E), while regular PBL was taught for the comparison group (C), as illustrated in *Fig. 1*. Dependent variables included academic achievement, professional abilities, creative thinking, problem-solving, and communication skills.

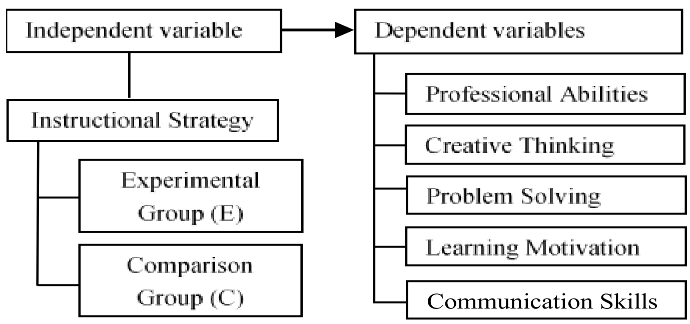

Fig. 1. Research design.

B. Participants

Participants for this study were recruited from the Hydraulic Engineering department of a large university in Taiwan. Fifty-four students registering for the course "Special Topic" course were divided into two groups. Twenty students joined the comparison group (C) receiving traditional PBL instruction, while thirty-four students joined the experimental group (E) receiving creativity-enhanced PBL instruction. The experimental group adopted the theme of "Reservoir Siltation" for course content, while the comparison group worked on an area of their interest as approved by the instructor. Each class involved collaborative learning activities (in groups of four or five) to guide students in completing tasks. However, in addition to regular PBL activities, the experimental group integrated both convergent and divergent thinking activities in order to both improve the quality of teaching and to stimulate students' creativity and innovative thinking.

C. Research Procedure

This "Special Topic" course lasted 16 weeks and involved one 50 minute session per week. Pretests and Posttests were administered before and after the intervention to evaluate the impact of the instructional strategy on the dependent variables.

The curriculum was designed to address the implementation of creativity training, while following the sequence of divergent thinking for idea generation and convergent thinking for selecting, focusing on an idea, and preparing a report for implementing a feasible solution. The stages of PBL from the creative problem-solving approach are presented in Table 1, along with the course activities for the experimental group. The experimental instructional treatment included four different creativity training session which were structured as group discussion activities. For divergent thinking, brainstorming and mind-mapping were utilized. During brainstorming, students discussed the problem of sedimentation in reservoirs and considered the potential causes and solutions to this issue, based on the background provided by the instructor and their previous coursework. Brainstorming involved thinking of as many ideas as possible for divergent creativity. Later, during the problem finding stage of the study, students used mind-mapping to represent their current knowledge of the sedimentation problem, adding new ideas or connections based upon their group discussion. Collaboration was critical for this divergent thinking activity, since multiple perspectives and opinions allowed the mind map to grow and a greater number of connections to be made.

Table I. Course schedule and activities

<table>
<tr><th>Week</th><th>Description</th><th>PBL Step</th></tr>
<tr><td>1</td><td>Pretests</td><td></td></tr>
<tr><td>2</td><td>Course Introduction
Grouping</td><td rowspan="2">Problem introduction</td></tr>
<tr><td>3</td><td>PBL introduction and
Group Discussion (Divergent Thinking)</td></tr>
<tr><td>4</td><td>In-class interview</td><td>Fact finding</td></tr>
</table>

5	Field Visit	
6	In-class interview	Problem finding
7	Group Discussion (Divergent Thinking)	
8	Independent Study	Idea finding
9	Individual Discussion	
10	Midterm Progress Report Presentation Skills	
11	Group Discussion (Convergent Thinking)	Solution finding
12	Individual Discussion	
13	Individual Discussion	Acceptance finding
14	Group Discussion (Convergent Thinking)	
15	Individual Discussion	
16	On-site Rehearsal	
17	Final Presentation	
18	Posttests	

In terms of convergent thinking, the experimental group used the SCAMPER technique to work on solution finding, by examining the results of mind mapping through the process of asking questions about existing ideas and asking for the generation of more relevant ideas through the following prompts: substitute; combine; adapt; modify; put to another use; eliminate; or reverse. For the acceptance finding stage of the experiment, students utilized the card exchange technique, wherein ideas were written on flash cards and categorized and arranged on the table top in order to identify contradictions and determine remaining information needs in order to formulate a final consensus on a solution.

For the comparison group, group discussion were also key to the PBL approach, but creativity exercises were not included. An overview of the differences between the experimental and comparison groups is included in Table II.

Table II. Course schedule and activities

Instructional Activities	Instructional Group	
	Comparison Group:	*Experimental Group:*
Content delivery	PPT-assisted instruction (20%) from guest speakers	PPT-assisted instruction (10%)
	In-class interviews (10%)	In-class interviews (10%)
Group Discussion	Small group topical discussion and class presentation (25%)	Small group topical discussion and class presentation (15%)
	Teacher Feedback (5%)	Teacher Feedback (5%)
Creative thinking and Problem solving tasks		Divergent thinking activities (10%)
		Convergent thinking activities (10%)
Extension activities	Field trip (10%)	Field trip (10%)
	Independent study (25%)	Independent study (25%)
Assessment	Project Presentation (5%)	Project Presentation (5%)

D. Data Collection and Analysis

The dependent variables were evaluated by students' final grade, for academic achievement, and by a series of rubrics evaluated by four representatives who are in their fields for more than five years from academic, industrial, and government domains. The rubrics were developed by the researchers, in cooperation with the experts. Experts received training on using the rubrics and evaluated a set of twenty reports before achieving an inter-rater reliability of 91%. Independently, the experts then blindly evaluated students final reports without being informed the course were divided into two groups, with the average of expert scores being used. This approach is based on Amabile's consensual assessment technique [9],, wherein the opinion of expert judges is considered more valid than the use of quantitative tests, such as divergent creative thinking tests, because the object of evaluation is an actual work or product. A sample item from the rubrics are provided for each of the tests, as shown below.

- Professional ability: "The student covered the topic in depth."
- Creative thinking: "The project demonstrates fluency, representing a number of appropriate concepts."
- Problem-solving: "The proposed idea is feasible."
- Expression ability: "The content of the report used clear logic and appropriate content."

Data were analyzed using t-tests for academic achievement (since no pretest was administered), and MANCOVA to analyze the above four categories of the expert panel rubrics.

IV. Results and Discussion

MANCOVA analysis was conducted, using pretests as covariates. The model was significant (*Wilks' Lambda* = 0.129, $F = 74.52$, $p = .00$, $\eta^2 = .87$) and the analysis found significant effect for professional ability ($F = 23.00$, $p = .00$, $\eta^2 = .32$), creativity ($F = 77.70$, $p = .00$, $\eta^2 = .62$), and problem solving ($F = 72.60$, $p = .00$, $\eta^2 = .61$), but not for communication skills ($F = 0.88$, $p = .35$). An effect size of $\eta^2 > .14$ is considered a large effect size [19]. Post hoc analysis and interpretation for each of the subscales of the expert panel appears as follows.

1) Professional ability

Post hoc analysis revealed that the adjusted post-test scores were greater for the experimental group ($M = 7.83$, $SD = 0.27$) than for the comparison group ($M = 6.74$, $SD = 0.13$), with a large effect size. The impact of the creativity-integrated PBL, as compared to regular PBL can be explained partly by the emphasis on group collaboration activities which involved the generation (divergent thinking), selection and refinement (convergent thinking) of solutions which were based on real-life and authentic problems. This is in line with the suggestions of authors who advocate explicit creativity activities for fostering learning outcomes [16] and authentic PBL with a high degree of collaboration [18]. Furthermore, the experience of working in teams to solve problems through these activities was somewhat similar to the professional context in which engineers collaborate to solve problems, thus impacting the professional skills necessary for future engineers.

2) Creativity

Post hoc analysis revealed that the adjusted post-test scores were greater for the experimental group ($M = 9.61$, $SD = 0.12$) than for the comparison group ($M = 8.15$, $SD = 0.10$), with a large effect size. The impact of the creativity-integrated PBL, as compared to regular PBL is evidently due to the creativity activities included in the experimental course design, but likely most attributable to the divergent thinking activities, since the rubrics evaluated attributes such as fluency, originality, and openness, but also elaboration, which would be associated with convergent thinking activities such as the SCAMPER and card exchange techniques. The emphasis on creative activities based on real-world solutions resulting in social benefits were designed on the suggestions of many creativity scholars, which led to an improvement in creative thinking [7], [8], [5]. However, the collaboration and brainstorming components could add extra time for the experimental group, which may bias results.

3) Problem-solving

Post hoc analysis revealed that the adjusted post-test scores were greater for the experimental group ($M = 12.03$, $SD = 0.21$) than for the comparison group ($M = 9.68$, $SD = 0.15$), with a large effect size. The impact of the creativity-integrated PBL, as compared to regular PBL) is also related to the nature of the convergent creativity activities, which emphasized the generation of feasible, usable, and effective solutions. The convergent thinking activities built on divergent thinking activities which were both reliant upon students background knowledge. Thus, through an emphasis on real-world problems and their solution through creative problem-solving [15], [18], students were able to improve their ability to develop effective and feasible approaches to finding causes, solutions, and ways to prevent problems (all elements which were evaluated by the expert panel rubrics).

4) Communciation skills

The lack of significant difference between the groups in terms of communication skills may be due to the fact that the creativity activities did not emphasize communication any more than the comparison group discussions. Thus, both groups learned through the PBL process and had ample opportunities to discuss, make presentations, and even interview guests.

V. Conclusions and Recommendations

This study demonstrates how a creativity-enhanced PBL can improve students' professional ability, creativity and problem-solving, as compared to regular PBL approaches, even resulting in higher academic achievement. By adopting a real-life problem and embracing the social context which is necessary for learning [9], [10], [11], particularly in terms of improving creative problem solving, our approach was effective in providing the type of nurturing environment, providing background knowledge and motivation for students to engage in deeper thinking [6]. The results of the study can also be replicated in other engineering domains, adopting real-life problems from other areas.

Acknowledgment

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