Introducing Creativity into Engineering Capstone Courses
A Project-Based Learning Approach

Pao-Ann Hsiung[+O], Ren-Hung Hwang[+], and Yau-Jane Chen[*]
[+]Dept. of Computer Science and Information Engineering
[*]Graduate Institute of Curriculum Studies
National Chung Cheng University, Chiayi, Taiwan
[O]E-mail: pahsiung@cs.ccu.edu.tw

Conference Key Areas: Engineering Education Research, Sustainability and Engineering Education, Curriculum Development

Keywords: Capstone course, creativity, project-based learning

INTRODUCTION

In most engineering curriculum designs, a capstone course in the junior and senior years tries to assess the capabilities of a student after at least five semesters of engineering education. Team-based projects are developed during the course. Technology readiness level (TRL) is often used to assess the technical merits of the projects. However, it is often found that the projects suffer from a lack in creativity. Most projects are mere implementations of existing technology, with limited innovation. The outcome of such a capstone course is that the students are not fully trained to cope with the rapidly changing technological environment. In this work, we investigate on how innovation can be inseminated into capstone course projects through training in creativity. A novel *creative Project-Based Learning* (cPBL) is proposed and implemented. The results from applying cPBL to a group of students in the Department of Computer Science and Information Engineering at the National Xxxxx Xxxxx University are promising because creativity scores evaluated from students' capstone projects by internal experts were higher for the experiment group as compared to the control group, in particular, for low creativity students.

1 MOTIVATION AND GOALS

In most undergraduate engineering degree programs, after 5 semesters of study students are required to work in a team of at least 3 persons on a technical project so as to digest and integrate all the subjects learnt in the previous semesters. The work on such an undergraduate project is designed as a 2-semester course that is generally termed as a *Capstone Course*. Normally, students take it in the 6th and 7th semesters. The education goal of this course is to make students capable of applying all learnt knowledge and skills into a comprehensive project, with some innovation.

Recently, the accreditation requirements for engineering curricula [1] has included the design of a *capstone course* as a required condition for approval. Most engineering departments have also included such a capstone course as a requirement for graduation. The importance of this course is thus obvious. However, the current design of most capstone courses has not been very successful in training students in design innovation because most of the projects in the course are simple implementations of existing technology, with very limited innovation. As a result, students when graduating from undergraduate programs are not yet capable of innovation; however, creativity has already become a basic required skill in today's rapidly changing technology and science. Take for example the design of an MP3 decoder, which a group of students could accomplish in a project by implementing an existing decoding algorithm, without any innovation. However, the market currently demands an MP3 decoder that has a smaller memory footprint and is more efficient in power usage. Given this market-induced restriction, students need to come up with a more innovative algorithm for MP3 decoding. At this point, creativity plays a major role in design success and market share holding.

Creativity is a response to an open-ended problem, in the form of a concept, a methodology, or a product. For example, the above-mentioned design of low-power low-memory MP3 decoder is an open-ended problem, with various ways in which the design can be realized and thus creativity is required. Starting from Mihaly Csikszentmihalyi's *Systems Model of Creativity* [2] to Teresa Amabile's *Componential Theory of Creativity* [3], creativity has been studied extensively. In general, the stimulating factors leading to creativity can be classified into individual (task motivation), social environment, and domain skills. For example, Csikszentmihalyi's Systems Model of Creativity focuses on the person (individual), the field (social), and the domain, while Amabile's Componential Theory of Creativity emphasizes the importance of intrinsic task motivation (individual), the social environment, the creativity-relevant processes, and the domain-relevant skills. Based on this observation, creativity can thus be introduced into the capability training of students in the capstone course by embedding the three creativity factors, namely task motivation, social environment, and relevant skills, into course design.

Project-Based Learning (PBL) [4] is often the main methodology used to train students in development of projects in the capstone course. PBL has been applied widely at various levels of education. PBL is a model for student-centered investigative learning in the form of a team project. In contrast to didactic learning, PBL emphasizes realistic hands-on experience with real-world constraints. For example, the low-power and low-memory footprint constraints for MP3 decoder are real-world constraints that might not be normally considered in theoretical courses; however, they will be considered in design or research projects.

The goal of this work is to introduce the three factors of creativity into PBL so that capstone course students can benefit from the creativity training. A novel *creative Project-Based Learning* (cPBL) is thus proposed in this work. Application of cPBL along with field experiments demonstrate its effectiveness in elevating creativity in students.

2 CREATIVE PROJECT-BASED LEARNING

The goal of this work is to propose and implement a method by which creativity can be enhanced for junior/senior undergraduate engineering students. Targeting at the capstone course, a *creative Project-Based Learning* (cPBL) [5] approach is proposed, where creativity-enhancing pedagogical techniques are introduced into a conventional project-based learning (PBL) method. PBL has been applied to various domains including software engineering [6], science [7], literature [8], education [9], and the social behavior of special education students [10].

The traditional PBL method as depicted in Fig. 1 includes 5 steps, namely preparation, implementation, presentation, evaluation, and revision. Preparation involves target problem selection and background preparation. Implementation constitutes the core work performed to solve to the target problem. Presentation includes the written and oral dissemination of project results. Evaluation is the assessment of the technical merits of a project. Revision is the final amendment based on evaluation, before the project results are delivered. This systematic workflow helps students to solve a target problem and achieve desired results. However, as we can see from the workflow, the solution to the problem could be a simple realization of an existing technology. Creativity could be very limited in the learning process. cPBL was thus created to address this issue. In the rest of this section, we will describe how cPBL was designed and implemented. In cPBL, a 2-phase approach is adopted, along with two checkpoints.

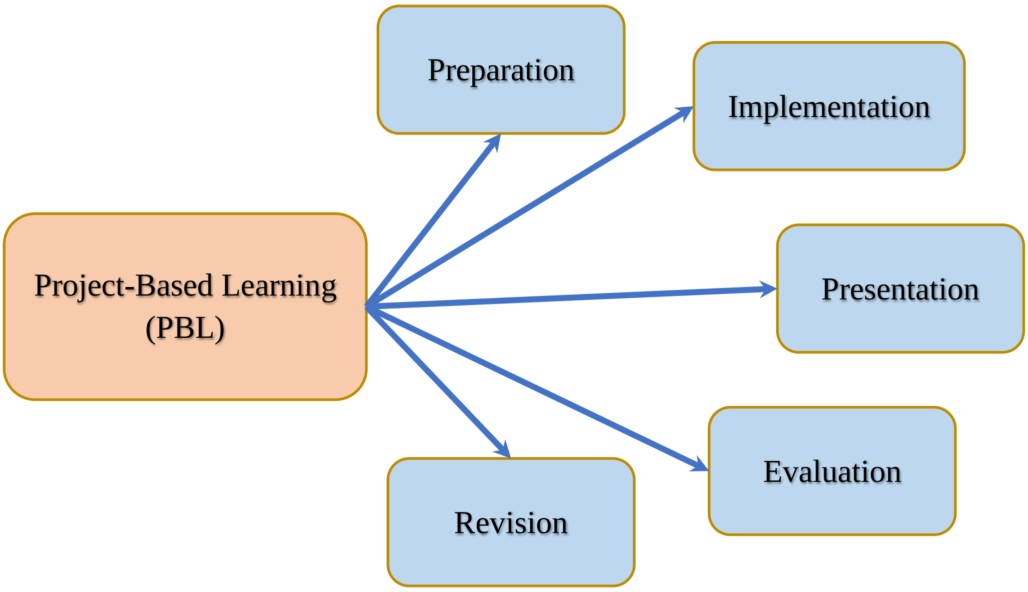

Fig. 1. Traditional Project-Based Learning (PBL)

2.1 Two-Phase Approach

The proposed cPBL method is designed as a 2-phase approach, including (a) *preparatory* phase in the form of a 1-semester course on skill-oriented training (domain-relevant and creativity relevant) and (b) *practical* phase consisting of a 2-semester course on capstone project design that should culminate in a demonstrable product. Thus, the span of cPBL is 3-semester, of which the preparatory phase is optional.

The cPBL method as depicted in Fig. 2, consists of the preparatory phase called Skill Development, while the practical phase is an extension of the 5 steps from PBL. The skill development step is performed in another preparatory course prior to the capstone course, while the practical phase is carried out in the capstone course itself. In the rest of this section, we will discuss the details of these two phases.

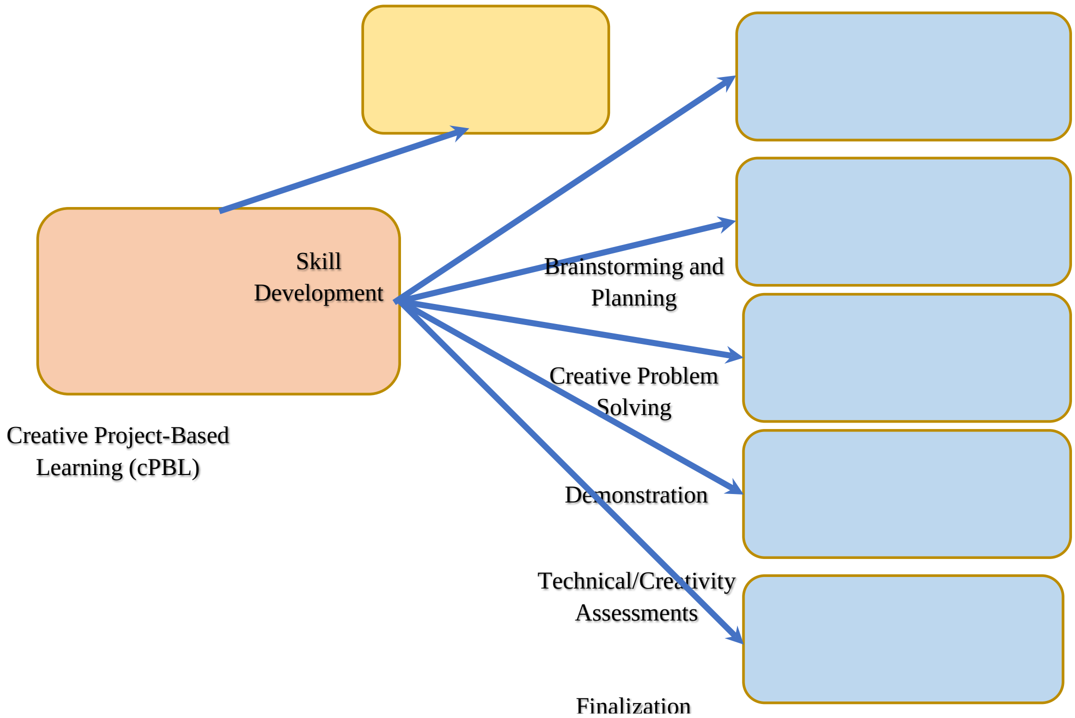

Fig. 2. Creative Project-Based Learning (cPBL)

2.2 The Preparatory Phase

The preparatory phase of the proposed cPBL method is mainly skill development, as depicted in Fig. 2. It consists of two parts, namely domain-relevant skill orientation and creativity-relevant skill orientation. The main goal of the preparatory phase is to prepare the students for the capstone project. Among the three creativity factors, this phase covers the *relevant skill training*, the other two are covered in the practical phase.

For the *domain*-relevant skill orientation, pedagogical techniques consist of presentations of capstone project themes given by project advisors, workshops on project management techniques by project managers, work experience sharing by alumni, and globalization and sustainability seminars by industry experts. The first two, namely theme presentations and project management focus on intrinsic development, where students can get an overview of all possible project themes and also how a project can be conducted. The latter two, namely alumni experience and industry seminars focus on social development, where students can get an overview on the future working environment and how to cope with such an environment. In summary, the four techniques employed in the preparatory phase help students to cope with the requirements of creativity both intrinsically and socially.

For the *creativity*-relevant skill orientation, pedagogical techniques involve short courses on the basics of intellectual property, technical patent writing, how to go from technical creativity to patents, and 6-3-5 brainwriting method training. A major element in the success of technical patents is creativity. The degree of innovation in a patent is often an indicator of how well the patent will be accepted in the industry and the market. Patents play a critical role in technology innovation in the industry. It is often seen that a company with a large number of useful patents can not only survive in the industry race, but can also make a larger profit. Nevertheless, most engineering students are not aware of the importance of patents, nor do the students know how to create or write a patent. To transform the creativity in a project into something tangible that can be reused across future designs, students need to learn the art of patent creation. Thus, in the preparatory phase, we invite patent office directors to come to train our students on the basics of intellectual property, how to transform technical creativity into patents, and how to write patent applications.

2.3 The Practical Phase

The practical phase of the proposed cPBL method is an extension of the traditional PBL method. Each of the 5 steps in PBL is extended such that creativity is not only blended into capstone project management, but also assessed and compared. The goal of the practical phase in cPBL is to train students in not only systematically solving a target problem, but also solving it *creatively*. Corresponding to the 5 steps of PBL, the practical phase of cPBL consists of brainstorming and planning, creative problem solving, demonstration, technical/creativity assessments, and finalization.

Besides the relevant skill training covered in the preparatory phase, the other two factors, namely *task motivation* and *social environment* are covered in this phase. Task motivation is induced in the first two steps, namely brainstorming and planning, and creative problem solving, through creativity-oriented activities so as to drive intrinsic task motivation in the students. Social environment is induced in the demonstration and technical/creativity assessments steps, through the involvement of industry experts, creativity experts, and market constraints. In the following, we explain how each step was designed and also supported by an in-house platform.

Brainstorming and planning involved scenario and motivation investigation for problem formulation. Creative brainstorming was introduced through two methods, namely SCAMPER (Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse) [11] method and six thinking hats method [12]. The six thinking hats method was already introduced in the preparatory phase and thus it is only applied in this step. The deliverables of this step include the specification of a target problem and related planning such as team organization, task allocation and scheduling, resource allocation, evaluation plan, and prior knowledge determination.

Creative problem solving involved creative design for realizing candidate solutions to the target problem. It is a research-oriented step to actually implement a feasible solution to the target problem. The theory of inventive problem solving (TRIZ) [13] was used in this step to come up with innovative solutions. Note that the training for other creativity-related skills was performed for the students in the preparatory phase already, including intellectual property basics, patent writing, and transforming technical creativity into patents. Thus, in this step of creative problem solving, the students need to not only come up with technical creativity, but also transform them into patents. The deliverables of this step include an implementation of a candidate solution to the target problem, related patents, and all kinds of software project management documents (specification, design, verification, configuration, etc.).

Demonstration is a presentation of the solution to the target problem implemented in the previous step. The presentation could be in the form of written report, oral presentation, and other ways of dissemination. Besides technical achievements such as the satisfaction of functional or non-functional requirements, technical *creativity* in the project results must also be made explicit in the demonstration. The deliverables of this step include a set of presentation slides, a written report, and other documents such as user manual, technical manual, test manual, etc.

Technical/Creativity assessments are a set of assessments of project results that are presented during the demonstration step. There are mainly two criteria for assessment, namely technology readiness level (TRL) and creativity level. TRL evaluates the technical merit of a project result, while creativity level assesses the degree of creativity. Different experts act as the evaluators for these two different assessments. Technical experts evaluate TRL, while creativity experts evaluate creativity level. The deliverables of this step include a TRL and a creativity level for a target project. Some other deliverables would be the feedback comments obtained from the evaluators on how the project results could be improved.

Finalization is the culmination of a working solution to the target problem, which has taken into account the feedback obtained from the previous two steps. The deliverables of this step include a complete working implementation of the target problem, along with all kinds of documents and assessment results from the previous steps.

3 EXPERIMENTS AND DISCUSSIONS

The proposed cPBL 2-phase approach was implemented on an experiment group of 28 students in the junior class of the Department of Computer Science and Information Engineering, National Chung Cheng University, Taiwan from September 2014 to January 2016. The experiment group consisted of 28 students, divided into 9 project teams, while the control group consisted of 52 students, divided into 20 project teams.

Table 1 shows the application of cPBL, along with all activities and cPBL steps. As we can observe, all three creativity factors are effectively introduced into the 3-semester long of preparatory course and capstone course.

Table 1. Application of Creative Project-Based Learning (Sep. 2014 to Jan. 2016)

Phase	**Date**	**Activities / cPBL Steps**	**Creativity Factor**
Preparatory (Sep 2014 to Jan 2015)	September 2014	Scrum Introduction	Domain-Relevant Skill
	October 2014	User Centered Design Introduction	Domain-Relevant Skill
	November 2014	User Interface Engineering Introduction	Domain-Relevant Skill
	December 2014	Big Data Introduction	Domain-Relevant Skill
	December 2014	Project Management	Domain-Relevant Skill
	January 2015	Patent Writing Six Thinking Hats	Creativity-Relevant Skill
Practical (Feb 2015 to Jan 2016)	February~March 2015	**Brainstorming & Planning** Seminar on Creative Teaching SCAMPER	Task Motivation Creativity-Relevant Skill
	April~October 2015	**Creative Problem Solving** TRIZ	Task Motivation Creativity-Relevant Skill

	June 2015	From Creative Technology to Patents	Creativity-Relevant Skill
	October 2015	Industrial Career Experience Seminar	Social Environment
	December 2015	**Demonstration** **Technical/Creativity Assessments**	Social Environment
	January 2016	**Finalization**	Social Environment

Two checkpoints were introduced into cPBL, one before and one after the capstone project design. At the first checkpoint, assessments of creativity of students were performed for both the experiment, as well as, the control groups using the Torrance Tests of Creative Thinking (TTCT), with four scales fluency, flexibility, originality, and elaboration. *Figure 3* shows the percentage distributions of the TTCT scores for both groups before cPBL.

At the second checkpoint, with the same scales, students' capstone projects were evaluated by two external experts and 10 faculty members as internal experts. The assessments allowed us to evaluate the effectivity of cPBL before and after the application of the pedagogical techniques. For example, the initial assessment was an indication of how the two groups fared in terms of their creativity levels before the practical phase of cPBL. The final assessment evaluated the creativity performance revealed from the capstone projects after the application of all pedagogical techniques in cPBL.

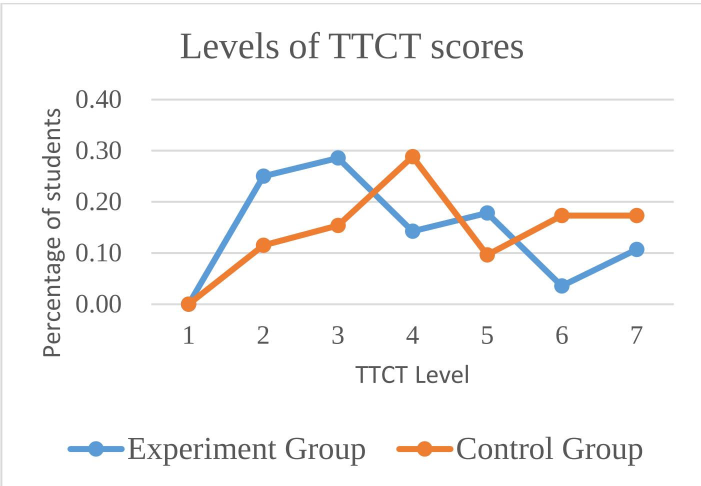

Fig. 3. Levels of Creative Thinking

With independent t-test analysis, both groups' TTCT scores were compared and the results suggest that statistically there is no significant difference between two groups, as shown in *Table 2*, before the application of creative thinking instructional strategies, mainly the SCAMPER and six thinking hats methods. However, after cPBL as shown in *Table 3*, creativity scores evaluated from students' capstone projects by internal experts were significantly higher for the experiment group as compared to the control group, in particular, for the low creativity-level students (*Table 4*). In other words, cPBL was effective in elevating the creativity levels of students.

Table 2
t-test of Torrance Tests of Creativity Thinking for all students

Group	*n*	$\bar{x}$	*SD*	*t*	*p*
Experimental	28	62.68	8.20	-1.955	.056
Control	52	66.44	8.23		

Table 3
t-test of Capstone Project Scores for all students

Evaluator	Group	*n*	$\bar{x}$	*SD*	*t*	*p*
Internal	Experimental	28	88.82	1.99	2.26*	.033
Experts	Control	52	86.74	2.92		

* $p < .05$

Table 4
t-test of Capstone Project Scores for Low Creativity-level Students

Evaluator	Group	*n*	$\bar{x}$	*SD*	*t*	*p*
Internal	Experimental	17	88.87	1.78	3.98***	.000
Experts	Control	24	85.96	2.90		

* $p < .05$, *** $p < .001$

4 SUMMARY AND ACKNOWLEDGMENTS

A novel creative Project-Based Learning (cPBL) was proposed and implemented to enhance the creativity of students while doing projects in capstone courses. A 2-phase approach was presented along with creativity-oriented steps. Experiments show that cPBL is especially effective for low creativity-level students.

This work was supported by a research project grant MOST103-2511-S-194-004-MY3 from the Ministry of Science and Technology, Taiwan.

REFERENCES

[1] Hsiung, P.-A. and Hwang, R.-H. (2015) “Refinement Measures for Engineering Education Accreditation from a Department Perspective,” in Proceedings of the 43rd Annual Conference of the European Society for Engineering Education (SEFI), France.

[2] Csikszentmihalyi, M. (2014) Systems Model of Creativity, Springer Netherlands.

[3] Amabile, T.M. (1996) Creativity in Context: Update to the Social Psychology of Creativity, Westview Press.

[4] Thomas, J.W. (2000) A review of research on project-based learning.

[5] Creative Project-Based Learning (cPBL) Platform (2016), http://pbl.cs.ccu.edu.tw/, National Chung Cheng University, Taiwan.

[6] Jeremic, Z., Jovanovic, J. & Gasevic, D. (2011). An environment for project-based collaborative learning of software design patterns. International Journal of Engineering Education, 27(1), 41-51.

[7] Krajcik, J. S., Czerniak, C. M. & Berger, C. (1998). Teaching Children Science: A Project-Based Approach. Mcgraw-Hill College.
[8] Au, K. H. & Carroll, J. H. (1997). Improving literacy achievement through a constructivist apporach: The KEEP demonstration classroom project. The Elementary School Journal. 97(3), 203-221.
[9] Tharp, R. G. & Gallimore, R. (1998). Rousing Minds to Life. Cambridge University Press.
[10] Horan, C., Lavaroni, C., & Beldon, P. (1996). Observation of the Tinker Tech Program stduents for critical thinking and social participation behaviors. Buck Institute for Education.
[11] Eberle, B., (1996), Scamper: Games for Imagination Development, Prufrock Press Inc., ISBN 978-1-882664-24-5.
[12] Six Thinking Hats (2016), https://en.wikipedia.org/wiki/Six_Thinking_Hats, Wikipedia.
[13] Theory of the Resolution of Invention-related Tasks (TRIZ) (2016), https://en.wikipedia.org/wiki/TRIZ, Wikipedia.