The Application of Multi-dimensional Learning Portfolios for Exploring the Creativity Learning Behavior in Engineering Education

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Abstract

The main objective of engineering education is to cultivate in students skills demanded by industries. However, those demanded skills largely fall into interdisciplinary experiences related to creative thinking due to emerging competitive markets. Therefore, today's engineering education should design such curriculum that inspires students' critical thinking so as to foster their creativity in order to solve today's sophisticated engineering problems. To achieve this purpose, based on creativity development theory, in this study we design and develop learning portfolio items constructed in a learning system according to learning objectives and teaching strategies of engineering project course. Students participated in learning activities following the instructor's planning and guidance and their learning behaviors to use a learning system were recorded in the database. Those attributes, such as frequency, sequence, and association of learning behavior were identified through a structured arrangement and statistical analysis. In addition, those key learning activities that inspire the students' creativity along with the creativity assessment results were discovered. According to our findings, high creativity students proceeded with active exploration during learning more frequently compared to low creativity students. The data analysis also showed more instances of independent thinking created by high creativity students, which resulted in better problem solving skills. As for the cognitive level, both the low and high creativity students demonstrated that they are able to apply and analyze newly learned information; however, more high creativity students were able to reach Evaluate cognitive level during learning activities.

Introduction

The objective of engineering education is not only to enrich students' engineering knowledge but also to enhance their interest in engineering curriculum through efficient teaching strategies, learning activities, and technology-assisted learning, so that students are able to demonstrate relevant knowledge and meet requirements for future work [1]. Unlike science education, engineering education aims to train talents equipped with a practical engineering knowledge and skills to integrate theory with practice [2]. Therefore, the curriculum of engineering education must match the needs to resolve real-world sophisticated and authentic problems. Moreover, the curriculum of engineering education needs to cultivate students' capability not only of deep perspective to a particular problem but also divergent thinking.

This view is supported by the theory of Conceptual Learning and Development (CLD), which suggests that taught theoretical concepts should be linked to related engineering problems [2]. With the rapid change in the structure of the competitive market, those talents who are capable of embarking on independent design and skillful in innovation, development, and thinking are urgently expected in the industrial circle. To satisfy the industrial needs of training interdisciplinary talents, many schools have emphasized the following aspects in their curriculum of engineering education: (1) to equip students with the basic knowledge of engineering; (2) to develop students' creativity and problem-solving ability; (3) to develop students' ability of integration and operation of systematic engineering. Shortly, the aim is to cultivate students the skills of collecting, analyzing, judging, integrating, and applying information, creative thinking, self-examination and adaptability through well-planned creative thinking and integral courses. Therefore, what courses and learning activities should be provided to students that foster their abilities of innovative and creative thinking as well as their abilities to apply newly learned knowledge to resolve complicated real-world engineering problems becomes the underlying issue in the engineering education today.

However, for creativity itself, the interpretation is quite diversified and can be viewed from different angles, depending on a certain field or people. For instance, some regard creativity as the ability to invent things; some deem it as divergent thinking; some see it as imagination[3]. Creativity was defined in related literature as the ability to create something original, and it is a feature and ability of those who are creative [4, 5]. Nevertheless, most of previous studies and scholars took works and products as the standard in the evaluation of one's creativity[6, 7, 8, 9]. Aside from what creativity is, the behaviors leading to creativity, the frequency, relevance and procedure of creativity, the correlation between learning behaviors and creativity, and the difference between those with strong creativity and those with weak creativity must be underlined in the education on creativity[7], so that teachers would be able to offer appropriate educational resources and guidance.

Learning portfolio refers to a systematic and targeted collection of the information about students' learning procedure and behaviors during a certain learning period. The information can be collected according to curriculum, strategies, content, and design and planning of assessment[10]. A detailed and complete learning portfolio can be used by students for self-examination, self-improvement and practice. It can also be employed by teachers to unveil some issues in learning process of students and to react to students' needs, provide guidance or conduct assessment [11]. Thanks to today’s digital technology, those learning portfolios now can mostly be collected through a learning management system. The advantage of digital learning portfolios is that various information can be integrated, recorded, and presented in various forms. Moreover, computer network can be taken as an information circulation platform to enhance the storage, transmission, management, and application of the information in learning portfolios [12]. Besides the infrastructure for recording portfolios, a methodology to dynamically record and analyze those data collected in response to learning environments and learning conditions is essential for the development of students' creativity in learning. A sound analysis on learning portfolios and exploring those links among learning behaviors will substantially lead us to discover the factors that motivate creativity and obtained findings can be used by educators for teaching, guidance, and assistance.

Therefore, this study explores two analytic factors: learning behavior and cognition portfolio in light of the theory of creativity development. According to the instructional outline and learning objectives of the engineering curriculum, in this study we introduce the project based learning and the SCAMPER teaching strategy. Besides, we developed a learning system that enables students to participate in our learning activities and it also records students' learning portfolios which includes their learning behaviors during activities. Using a learning system, participants joined the project course activities under the guidance and plan of the instructor. We collect data of students' participation in learning activities using a learning system and analyze data to explore and discuss conditions, relations, and procedures of the formation of creativity. Moreover, we analyzed the influence of the frequency, relevance, and sequence of the behaviors on students' creativity. A dynamic and real multi-directional portfolio record and information allowed us to reveal the factors and conditions for motivating the creativity of students. Furthermore, behavioral patterns of creativity were used by teachers for purpose of teaching assistance and immediate response, so as to develop students' creative thinking, promote the combination of their creativity and imagination, and enhance the innovative application of newly learned knowledge to solve real-world problems in engineering education.

Learning System

In this study, the Moodle platform (Version 2.8.3, released in February 2015) was employed as the learning system. The Apache and PHP were used as the web page server; the MySQL was employed as the database. The fore end of the Moodle platform was presented to students in web based page and developed with modularized architecture which consists of a core module and a plug-in module. Each module comprises a user interface and a program library. When some functions are added, the mechanism of the Moodle plug-in module is the most frequently-used, which connects the newly-added modules with the original Moodle core. Moodle has different types of plug-in modules. To meet the need of the teaching design and support the project based learning as well as the SCAMPER teaching strategies, we adopted the Activity plug-in module in the learning system to incorporate the necessary functions. The overall system architecture is shown in Figure 1. Both teachers and students could use the Moodle learning system through the Internet. Using the features of integration and modularity of the Moodle, the project based learning and the SCAMPER teaching strategies were be effectively implemented. Moreover, to ensure that students attend simultaneous interaction and discussion through distant face-to-face online meetings, an online meeting module Joinnet was plugged into the Moodle learning system. In addition, students used diverse learning assistance tools to explore topics and interact with classmates. Through the construction-based and divergent thinking strategies, students developed meta-cognition, extended thinking, problem-solving ability and innovation skill.

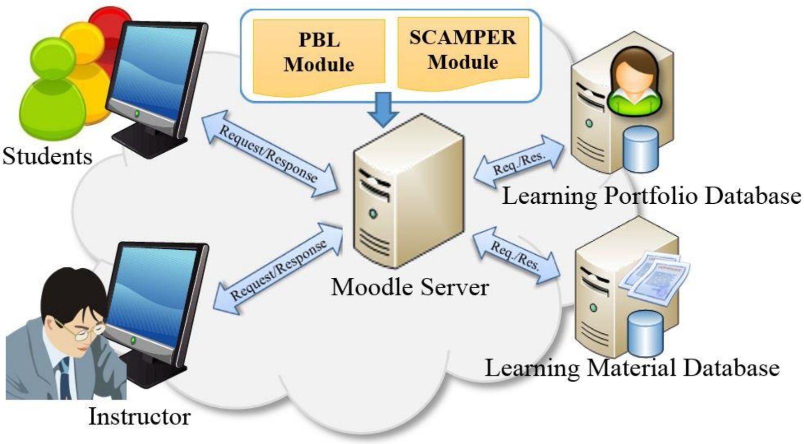

Figure 1. System Architecture

The system interface and functions for students are planned and designed according to the teaching procedure. The system interface is shown in Figure 2. The basic functions in most learning platforms were also included in the system, such as: schedule reminder, discussion forums (asynchronous), video conferencing (synchronous), assignment submission, feedback evaluation and so on. Particularly, the project based learning which consists of five stages was implemented in the learning system: Preparation (P) - Implementation (I) - Presentation (P) - Evaluation (E) - Revision (R), and SCAMPER teaching strategy which includes seven thinking-based dimensions: Substitute (S), Combine (C), Adapt (A), Modify (M), Put to other uses (P), Eliminate (E) and Rearrange (R). At each stage, students were able to use the activity module provided by the system to add new tasks and topics for discussion. The diverse learning tools and the immediate guidance on the platform helped students effectively achieve project tasks. Through the participation and engagement in the activities, students were encouraged to attend external and inter-group discussions, extend thinking, develop diverse perspectives and further toward to the high-level cognitive learning skills.

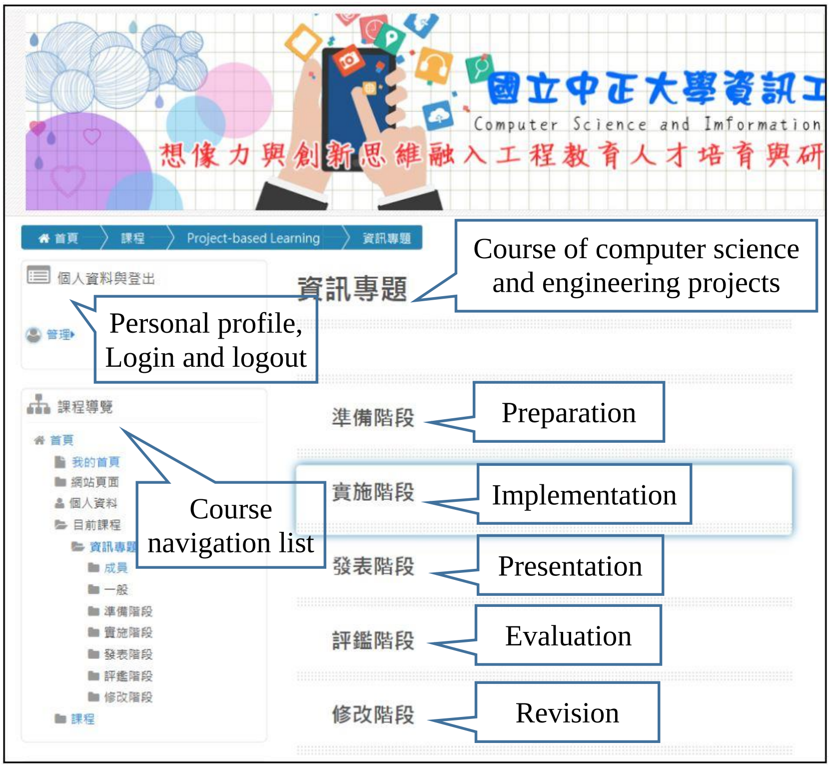

Figure 2. Interface of Moodle learning system

Research Design

Participants

The participants in this study were 54 first year university students who took courses on Computer science and Engineering projects I and II. Students were divided into nine groups with 6 students in each group. Students completed the five stages project course on the Moodle learning platform. The appropriate guidance on different objectives in the five stages can help students gradually develop their thinking from a divergent one to a convergent one and address problems in group discussions. Additionally, through exchange of information and discussion among group members, students' imagination, inference, thinking, and problem solving can be promoted because of different faiths and values from different members. Through different ways of thinking, group members will have the learning process involving analysis, deduction, criticism and demonstration. With the knowledge acquired from others and assimilated, they can make efforts to achieve innovation and develop suitable, meaningful and valuable creativity. In order to make all groups embark on the learning actively in the project activities, students were told that the degree of their involvement will be counted into their final course grade.

Experimental procedure

The Computer science and Engineering projects I and II were taught in two semesters, and each semester lasted for 18 weeks. There were two study hours per week. The whole experimental procedure is shown in Figure 3.

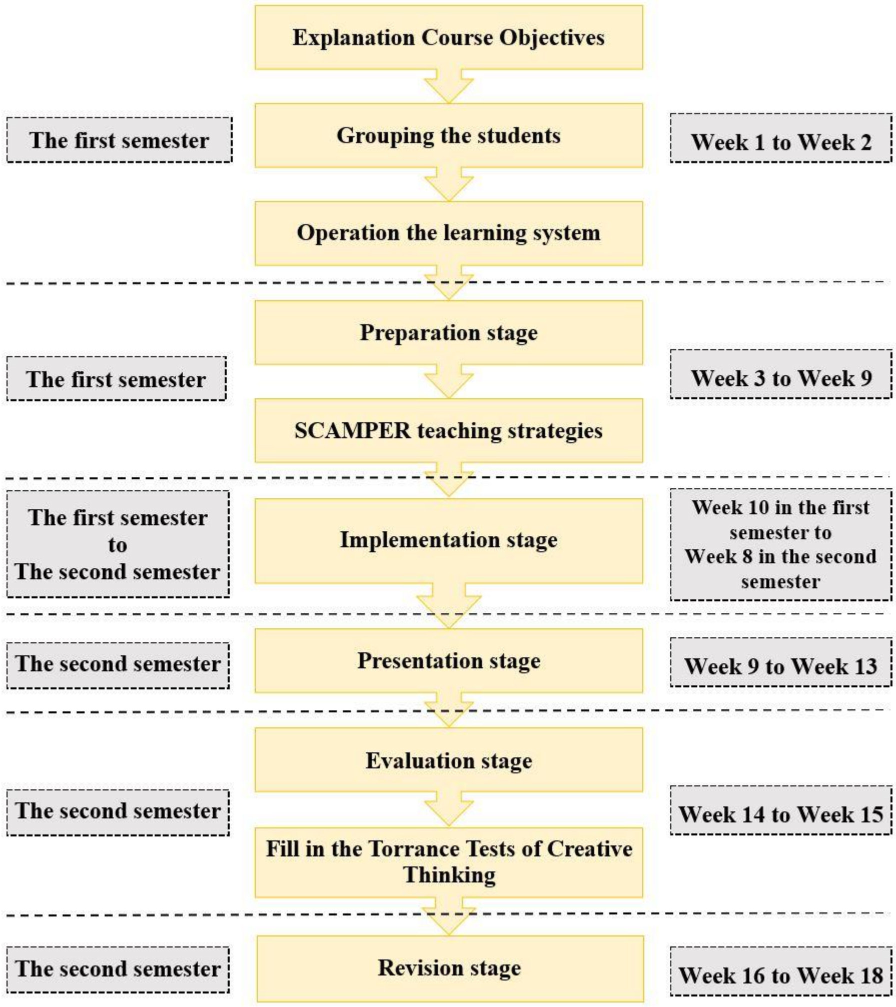

Figure 3. Experimental procedure

During the first and second weeks of the first semester, all students stayed in a computer classroom; meanwhile, the procedure and contents of all stages of the learning activities were introduced so that they have a general idea of the course format and followed a clear outline in the activities. Also, the students were divided into groups to practice the operation of the learning system in order to be prepared for the learning activities. Starting from the third week in the first semester, the project-based learning activities and the SCAMPER teaching strategies were carried out until week 9 of the same semester. During this period, all groups had to use the tools on the learning platform to discuss the direction, scope, objective, item, planning of topics and available resources, and so on. The projects of each group are shown in Table 1.

Table 1. The projects of each group.

Group	The name of the project
1	Market guidance system
2	Malicious behavior analysis on the social network
3	Microprocessor design of adaptive regulator
4	Automatic parking Path planning and traction control
5	The control of multi-axis aircraft
6	Energy-efficiency management of smart appliance
7	Caching using Software-Defined Networking (SDN)
8	CacheFlow in Software-Defined Networks (SDN)
9	Security of IoT (Internet of Things)

The SCAMPER teaching strategies included seven thinking-based dimensions and they could eliminate and rearrange students' understanding of existing concepts and motivate them to come up with new ideas, so as to help students review the possibility of any change to a current project and task arrangement. The details of thinking-based dimensions are shown in Table 2.

Table 2. The seven thinking-based dimensions of SCAMPER.

Thinking dimensions	Thinking direction
Substitute (S)	Which items can be replaced with something else
Combine (C)	Which items can be combined toward a solution
Adapt (A)	Change some part of the problem to make it workable
Modify (M)	Modify attributes of items you are working on
Put to other uses (P)	Think the intention of the subject again
Eliminate (E)	Arbitrarily remove any items to approach core functionality
Rearrange (R)	Which items can be restructured and reordered, or even reversed in position

From week 10 of the first semester to week 8 of the second semester, the implementation stage was carried out. During this stage, projects were implemented according to students' planning, design and analytic work in the period of preparation and yet, project content was created. All groups uploaded and shared resources, they also attended asynchronous and synchronous discussions and followed their learning progress using various functions of the learning system. The students in this stage actively established and shared their learning information; therefore, they could have the sense of belonging and responsibility to face the problems. Through teamwork, group discussions, and collaborative learning, they were able to find out the knowledge and conceptual principles for problem solving. Then, group sharing and deduction led to solutions and cognitive understanding, which could lead to developing their critical thinking abilities. The presentation stage lasted from week 9 to week 13 of the second semester. In this stage, all groups were asked to publish and share results of their projects. Before the formal presentation, they could interact and exchange ideas in the system and submit relevant documents and oral reports through the submission function. In the presentation process, all groups could present and share their projects in diverse forms. Other groups had to give an immediate feedback and suggestions after a presentation was finished. The evaluation stage took place from week 14 to week 15. The evaluation objectives of project-based learning were as follows: (1) results of learning are evaluated to reveal effects of learning, advancement in knowledge, and benefits of the technology, and (2) the learning process is evaluated to find out how students' problem-solving abilities and interpersonal interaction were advanced[13]. Therefore, this study used three criteria to evaluate results of project achievements: self-evaluation (25%), peer evaluation (25%), and expert evaluation (50%). Evaluation results were uploaded to the learning system. Moreover, students were required to fill in the Torrance Tests of Creative Thinking (TTCT) which shows the degree of students' creativity. Week 16 to week 18 was the revision stage. The students reviewed their abilities of communication, coordination, cooperation, and criticism during the project construction and presentation according to feedback provided in the evaluation stage, so as to enhance their potential of self-examination. In addition, the students modified project reports and improved their learning ability according to feedback and mutual evaluations; then, they could develop necessary professional judgment and problem-solving ability for their future career.

Assessment tools

(1). Course grades

After the project courses, all students received a total grade based on self-evaluation, peer evaluation, and expert evaluation. In order to understand differences among the three evaluation methods, this study adopted the statistical analysis for the evaluation and exploration. The criteria content of three dimensions were created by three professional instructors according to the requirements and objectives of the courses, and then were revised by two experts, so that it had criterion and construct validity.

(2). The Torrance Tests of Creative Thinking

The Torrance Tests of Creative Thinking (TTCT) was developed by Torrance et al. [3]. TTCT is the most widely-used creativity test nowadays and applicable to people of all ages. TTCT consists of the language creation thinking test, the picture creation thinking test, and the sound and vocabulary creation thinking test. All these tests are organized and presented in the form of game, so the tests are relaxing ones. The students' performance in the TTCT indicates their creativity after the project-based learning activities and the SCAMPER teaching strategies.

(3). Learning Behavior

In order to understand whether the students' operation and interaction in the learning platform influence their creativity, and to find out the sequence of their learning behaviors, the frequency and procedure they operate the system as well as the relationship among these constructs, this study encoded, defined, and classified the recorded learning portfolios and then adopted the Lag Sequential Analyses (LSA). The classification items were as follows: Reading (R), Post (P), Response (RP), Upload (U), Download (D), Face-to-face meeting (F), and Calendar (C).

(4). Cognitive Process

Cognitive process dimensions were analyzed according to recorded students’ discussion in the discussion forum and video conferencing. According to Bloom's six cognitive process dimensions, this study used the phenomenographic analysis and MAXQDA11 which is a qualitative data analysis software to analyze records of discussion and videos for exploring the relevance and difference in the cognitive processes among students of different levels of creativity.

Research Results

Results of Course Grades and their Analysis

The difference among the three evaluating methods of the learning effect on the Computer science and Engineering project course are shown in Table 3.

Table 3. The grades of three evaluation methods.

Method	Self-evaluation	Peer evaluation	Teacher evaluation
M	86.13	82.62	86.5

The peer evaluation has the lowest score among the three evaluation methods, while the self-evaluation and expert evaluation share a relatively similar scores. Such result is consistent with the previous research done by Sung et al. [14] and Sadler & Good [15]. According to the observation of the instructors, the grades of learning activities results are included into this semester achievement. Because of competition, we speculate that a stricter standard was adopted in the peer evaluation, while a relatively lower standard was applied in the self-evaluation and teacher evaluation.

Analysis of Torrance Tests of Creative Thinking

The TTCT included three tests, lasting for about 40 minutes. Scores of the tests are classified into five dimensions, and the analytic results are shown in Table 4. The students got a higher score in the following three dimensions: fluency, abstractness of the title, and resistance to premature closure. Therefore, it can be speculated that the students developed fluent and diverse thinking through participating in the project-based learning activities and the SCAMPER teaching strategies. Meanwhile, they became able to grasp the essence of problems and developed the abilities of analysis and evaluation in the cognitive thinking; eventually they could keep open and rigorous thinking in face of diverse information and views in the process of information processing.

Table 4. The scores of the TTCT five dimensions

Dimensions	**M**	**SD**
Fluency	98.51	18.87
Original	61.34	16.54
Abstractness of the title	101.61	19.15
Elaboration	64.96	24.01
Resistance to premature closure	91.19	19.58
Average	83.53	12.61

Analysis of Learning Behaviors

The student behaviors during the project-based learning activities and the SCAMPER teaching in the learning system were recorded in the database. The information about the portfolios were analyzed to explore the students' operation and interaction in the project course.

Table 5. The LSA assessment results of two groups
(left: high creativity, right: low creativity)

	R	**P**	**RP**	**U**	**D**	**F**	**C**
R	966	1083	1380	694	898	30	30
P	1323	56	179	875	213	0	50
RP	1368	180	47	573	512	0	21
U	1182	852	969	571	198	15	26
D	1047	753	832	158	537	39	23
F	709	993	563	627	423	8	15
C	30	59	37	68	48	21	22

	R	**P**	**RP**	**U**	**D**	**F**	**C**
R	1421	676	773	388	532	5	12
P	856	34	76	409	198	0	15
RP	883	95	28	318	206	0	12
U	765	463	479	329	108	7	10
D	706	371	402	98	305	17	9
F	552	411	374	398	278	2	6
C	23	43	33	31	48	6	11

First, the students were divided into two groups according to the average score of TTCT, one group included students with high creativity and the other included those with low creativity. Then, the learning portfolios in the database were arranged according to the items of classification. Finally, the LSA was used to evaluate the sequence and frequency of all learning behaviors. The analytic results of the two groups are shown in Table 5.

According to the LSA results, the z score proposed by Allison and Liker was adopted for the statistical analysis and computation [16], so as to find out the relevance and significance of the learning behaviors. The analytic analysis of the two groups is shown in Table 6. The value which is greater than 1.96 indicates a significant relevance and a strong correlation between learning behaviors.

Table 6. The *z* score results of the two groups.
(left: high creativity, right: low creativity)

	R	P	RP	U	D	F	C
R	7.07	8.37	10.07	3.89	6.92	-9.95	-10.43
P	9.57	-7.47	-4.98	6.46	-3.16	-12.61	-7.17
RP	9.94	-4.86	-8.98	3.18	2.03	-12.56	-10.89
U	8.85	6.03	7.29	2.98	-4.15	-11.43	-10.66
D	7.93	4.97	5.76	-5.09	2.26	-9.11	-10.74
F	4.36	7.42	2.68	3.23	1.28	-11.87	-11.03
C	-10.03	-7.31	-9.23	-6.71	-8.56	-10.98	-10.81

	R	P	RP	U	D	F	C
R	10.84	3.56	5.43	0.08	2.15	-12.21	-11.23
P	6.12	-9.47	-6.16	0.67	-4.05	-12.98	-11.13
RP	6.64	-5.98	-10.53	-1.24	-3.67	-12.78	-11.25
U	5.29	1.56	1.76	-0.97	-5.31	-12.08	-11.52
D	4.03	-0.13	0.48	-5.91	-1.96	-11.19	-11.73
F	2.53	0.95	-0.03	0.13	-2.97	-12.37	-12.04
C	-10.74	-9.06	-9.45	-9.67	-8.77	-12.13	-11.65

We converted the results of the statistical analysis presented in Table 4 into Figures 4 and 5 in order to visualize learning behaviors and relationships among them.

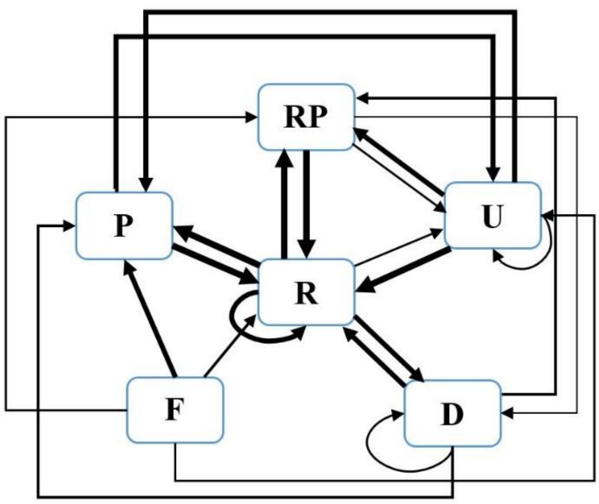

Figure 4. Behavior pattern of high creativity students

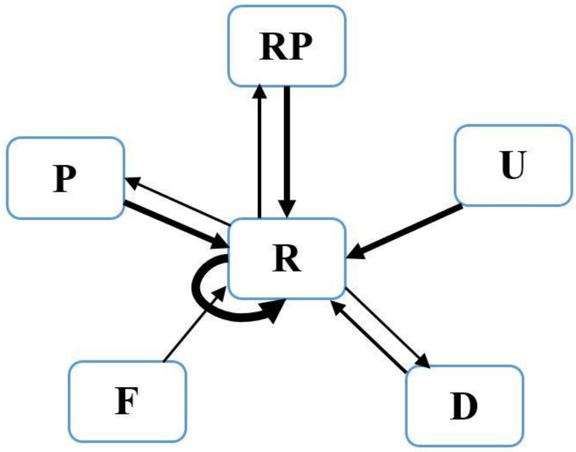

Figure 5. Behavior pattern of low creativity students

The thickness of the lines in the figures represent the strength of the relationship between two behaviors. According to Figure 4, the students with high creativity often made posts and response, and read relevant information in the learning system. Also, they actively interacted and discussed problems with their peers in the group to acquire the knowledge for problem solving. Moreover, they often made use of the upload and download functions to share the information they have collected and summarized, so as to promote group discussions, extend thinking, motivate diverse views, and develop creative thinking. On the contrary, the students with low creativity tended to read information in the learning system and made less posts and responses in comparison with the high creativity students. In addition, there is a high frequency of downloading information throughout the entire project course while the frequency of uploading information, discussion, and interaction was low.

Analysis of the Cognitive Process

The phenomenographic analysis and MAXQDA11 were adopted to encode, summarize, and analyze the records of the discussions in the discussion forums and video conferencing. Meanwhile, Bloom's six cognitive processes were used to explore students' cognitive development levels, and the results are presented in the form of the figures where the thickness of the lines indicates the relevance among the results. The analytic results are shown in Figure 6. According to Figure 6, the students with low creativity could effectively apply the knowledge and concepts they have acquired to the construction of project in the discussions and interaction in the learning system. Moreover, they could analyze and discuss the entire structure according to the activities of the project-based learning and the SCAMPER teaching as well as point out the relevance between parts and the entire architecture. Aside from possessing the abilities of application and analysis, the students with high creativity could make remarks and judgment according to the information and problems for discussion, which shows that they have developed the abilities of critical thinking and professional judgment (i.e. Evaluate level of Bloom’s taxonomy).

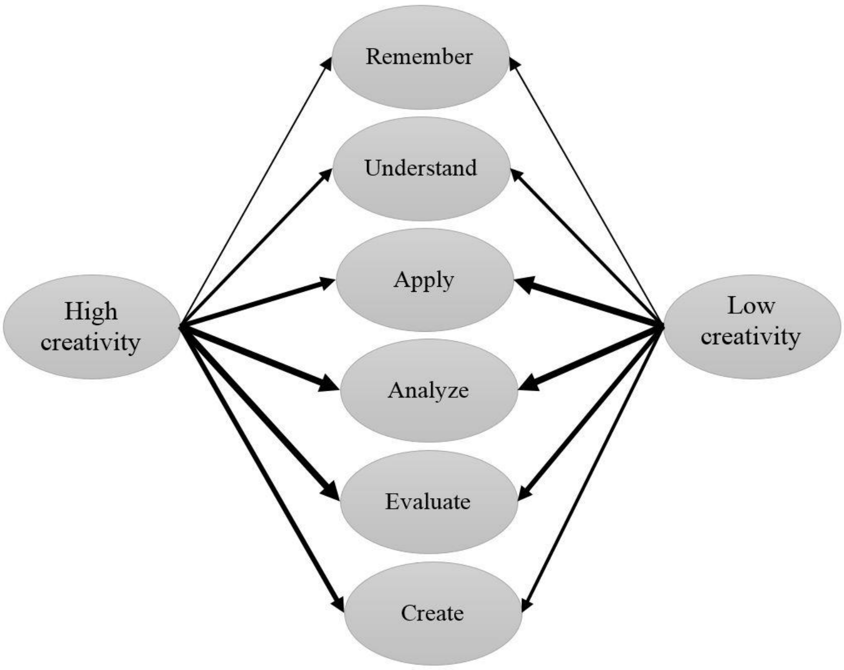

Figure 6. The analytic results of the cognitive processes

Conclusion and Future Studies

With the structure of the competitive market changes, there is an increasing demand for the thinkers equipped with interdisciplinary experience and strong innovation in the industrial community. Therefore, engineering education should aim to furnish students with the ability to solve engineering problems in a creative way. However, in the past, students' creativity was often evaluated according to result of products, and little attention was paid to their behavioral procedure in learning. If the rich information and value hidden in the learning portfolio in the learning system can be explored, it will advance studies on the development of creativity and the guidance for behavior. Therefore, this study established the Moodle learning system incorporated with the project-based learning and the SCAMPER teaching strategies. With the learning guidance and activity procedure on the learning system, students could have asynchronous and synchronous interaction and discussion. Through teamwork, group discussion and collaborative leaning, they could get problem solutions and deepen their cognitive understanding and thus develop the abilities of critical thinking and professional judgment.

According to the results of the experiment, the peer evaluation has the lowest score among the three evaluation methods because of the competition among peers, while the self-evaluation and the expert evaluation share a similar score. Additionally, the analysis of the learning behaviors show that most of the students with low creativity read and downloaded information in the learning system and interacted with peers in the platform to have diverse views and enhance their abilities of self-efficacy analysis; the students with high creativity were willing to seek, explore and analyze information, share it, and discuss problems in the learning system, so they show stronger curiosity and desire for knowledge, which drove them to imagine, reason, think and solve problems. According to philosophy and cognitive psychology, the behavior of the latter is a kind of creative activity [17]. Moreover, the analysis of the cognitive processes shows that the students with low creativity possessed the abilities of application and analysis in the asynchronous and synchronous discussions while the students with high creativity developed the abilities of critical thinking and professional judgment. Logical reasoning, creative thinking, and problem-solving skills are regarded as the operational skills of critical thinking by some scholars. However, there is relevance between creative thinking and critical thinking, i.e. how to maintain basic norm and recognize and exceed non-necessary norms within the relevant scope [18]. Therefore, effective development of critical thinking can promote the development of creative thinking.

According to the findings, diversified assessments imposed on project results can obtain a more objective evaluation and instructors are suggested to apply them. Moreover, in the computer science and engineering project courses, instructors are suggested to adopt more appropriate teaching strategies to encourage students to speak, discuss, and interact their ideas with others. Through the idea exchange between peers, students can bring out the wide range of views and ideas, and develop the ability of self-learning and self-reflection. Furthermore, the interactive process can enhance students' cognitive thinking skills, and even promote the development of critical and creative thinking.

This study is still on ongoing, therefore, we only offered basic information about the learning behaviors and cognitive process in the learning system. As for those factors such as cognitive style, cognitive load, and learning anxiety of students, we will explore them in the near future.

Acknowledgements

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