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The Educational Effects of an Introductory Engineering Design Course based on Creative Projects*

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The purpose of this study was to verify the educational effects of a mandatory introductory engineering design course wherein the students find their own project items and solve them using creative projects. Case studies, investigation through surveys, and weekly reflective journals have been performed in order to achieve this goal. The results of this research present the details of running the class and the outcomes of the student's projects; the educational effects and difficulties are analyzed. It turned out that brainstorming is very helpful for idea generation and patent searches are useful in the problem solving stage. The finding of real engineering problems regarding the project topics is the most difficult part of the project, however it strongly correlates to the improvement of the students' hard skills and promotes the perception of engineering problems in the sense of engineers, not as users but as suppliers.

Keywords: creative project; design education; educational effects of engineering design; engineering creativity

1. Introduction

As the requirement for engineers with creativity and problem solving capabilities has increased in our society, engineering education curricula have greatly changed. The contents of engineering design courses have been improved in order to meet the demands of competency of design, problem solving, and team work skills in the USA [1]. For example, all engineering freshmen at the University of Dayton take a design course which consists of standard modules [2]. Civil and environmental engineering modules are included in order to allow students to be able to define the issues in these areas and show their relationships to other engineering fields. These topics promote the integration of technical and non-technical issues; the classes include case studies, panel discussions, and laboratory work. Pennsylvania State University runs a design course for incoming students based on team projects. It is characterized by including hands-on activities, oral and written communication, in-class discussions, and ill-structured problems [1].

Design courses have become one of the main issues in engineering school curricula, since after 2001 at least 30% of the engineering courses need to be design courses according to the ABEEK (Accreditation Board for Engineering Education of Korea), which was introduced at that time [3]. The design curricula consist of introductory design, element design, and capstone design. The introductory design course is usually three credits and is offered by all engineering schools or individual departments. They are given to freshmen or sophomores and provide both the hard and soft skills required by the program outcomes specified by ABEEK. In terms of creativity, there is a lack of leading students that can determine needs and specify project items by themselves; it is commonly done by providing open-ended problems and thereby fostering the problem solving abilities in the course of projects. In this study, architectural engineering students undertook creative projects wherein they found their own problems and solved them. Case studies are presented here and the educational effects are also investigated. In this way, the points in question regarding design education based on creative projects are analyzed and through this the generalization to all design courses is sought.

2. The methodology of study

Case studies, effects analysis investigation, and the assessment of reflective journals and project reports from the author's course are used in this study. The case studies are taken from an introductory design course for architectural students at an engineering school in Inchon, Korea. Weekly reflective journals and project outputs have been checked and commented upon in the course. Afterwards a course

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survey was carried out in order to analyze the educational effects. The number of people replying to the survey was 44 even though a total of 49 students took the class. 37 (84.1%) of the respondents were male and 7 (15.9%) were female. Since this was officially a sophomore course, sophomore students made up the majority (77.3%) with ten (22.7%) others participating. Only three (7%) of the students had industry experience.

3. The case studies based on the creativity projects

This three credit course ran for sixteen weeks. The goal, as the introductory design course for students entering college, is to help students understand the concepts and processes of design and foster their ability to solve problems using strategic approaches for practicing creativity as a member of team. Lectures are given on design concepts and procedures and creative projects are assigned to offer opportunities in solving real world problems. All of the projects are performed by teams and reports at the planning, progress and final stages are presented to the entire class. Details of the course are presented in Table 1.

As this course is assigned on the first semester of sophomore, students had not have taken courses in their major and so were not accustomed on solving open-ended problems. As it is imperative to have the will and eye to find worthy problems in an engineering sense and to solve consequent problems as engineering students, the first project was *'to find and solve problems in terms of eco-friendly concept'* which needed a wide viewpoint. The second project was *'to make a successful proposal of an architectural room in a science and technology museum'* which had a more specific goal. Plans regarding the execution of these projects were required to be written and presented in order to make the process more systematic; these reports were collected at each stage of the projects and commented upon by the instructor. The instructor can ask questions and also make suggestions in the report comments. Online TRIZ training [4], theoretical lectures, and small tasks can be combined to instruct students who lack the ability for creative problem solving. Each team consisted of five students who remained together throughout the whole semester. The students' evaluation criteria are as follows: the criteria for the planning reports are composition, completeness, and style. Those for presentation are level of preparation and fluency competency. Completeness of components and contents, originality, references and editing are the criteria used for the final report. The evaluation of the whole team efforts were carried out based on self and peer evaluations for the common skills of the team activity and individual skills for the team dynamics; the result were reflected in their GPAs [5, 6]. The team projects are shown in Table 2. Their topics cover a wide variety. Most used patent searches and mind maps to select the subjects; two teams used TRIZ to solve their problems. Brainstorming was the most popular methodology for every team. Some members carried out the need analysis by customer surveys and visited experts when solving the harder problems they encountered.

4. The effects of design education based on creative projects

4.1 The effects analysis regarding the class

The results of the analysis regarding the changes in the students' perception during a semester shows that students considered brainstorming to be the most helpful method for creative idea generation (M = 4.11). They also became acquainted with the patent search method (M = 3.98) which was widely used in the problem solving process of the projects (M = 3.74). Students were asked to define a project subject as an engineering problem by themselves; this process was considered to be very useful in perceiving engineering problems (M = 3.91).

Table 1. The Course Schedule Details

Weeks	Contents	Remark
1 ~ 4	• Outline and introduction • Concept of engineering design, design elements and design process • Definition of problems, function, and idea generation • Engineering creativity concepts and ways to manifest them	• Team formation (2nd week) • TRIZ quiz from online TRIZ training
5 ~ 9	• Project for concept design – Submission and presentation of project plan – Submission and presentation of project results	• reflective journal (every week) • Midterm (8th week) • TRIZ quiz from online TRIZ training
10 ~ 16	• Design process management • Tips for final report writing of the project • Product design – Submission and presentation of project plan – Submission and presentation of project results	• reflective journal (every week) • TRIZ quiz from online TRIZ training • Survey after class (16th week) • Self and peer evaluation for the teamwork (16th week)

Table 2. The Student Project Summary

Team	Topic	Contents	Methods
1	Rotating window	Rollers and wires are introduced to support a shaft and make a 180° rotation in semi automatic mode	Patent search, TRIZ and mind map
2	Decrease of the heat from an outdoor heat exchanger of an air conditioner.	Cold water at 10ºC runs in a copper pipe between the fans and exchangers of an outdoor system to lower the air temperature	Brainstorming, visiting experts
3	Effective collection of recyclable drink cups	Improvement of the environment by the efficient collection of coffee cups	Customer survey, brainstorming, mind map, visiting a coffee house
4	Eco friendly far-infrared food leftover processor	Utilization of far-infrared rays : drying and sterilization, noise reduction, deodorization and cost efficiency	Customer survey, brainstorming, market analysis
5	Eco friendly lighting system	Eco friendly light collecting system for a living area with poor lighting	Brainstorming, mind map, survey, creating a prototype and testing
6	Eco friendly space generation by improving the water quality of a pond	Plants, truss structure dividing rain, solar powered fountain	Interview, Survey
7	Cost effective high efficiency solar power generation	Cost effective solar power system using mirrors and moving solar panels	Brainstorming, mind map, TRIZ
8	Energy saving by closing gap	PVA fibers on a window gap to save energy	Survey, brainstorming, mind map
9	Safe driving by clear view	Improvement of the moving mechanism and eco material on wiper to obtain a clear view	Survey, brainstorming, mind map
10	Re-smoking of cigarette butt	Design to alter the function of an ash tray and re-use the cigarette butt	Survey, patent search

Table 3. The Affirmative Effects of the Introductory Design Course

Items	N	Mean	Std. Deviation
Perception of engineering problems	44	3.91	0.71
Perception of patent search methodology	44	3.98	0.88
Usefulness of patent search	44	3.73	0.90
Pre knowledge of TRIZ	44	1.55	0.98
Usage of TRIZ in project	44	3.41	0.84
Interests in TRIZ	44	3.32	0.98
Usefulness of brainstorming for creative idea generation	44	4.11	0.89
Usage of mind map	44	3.70	0.98
Usefulness of mind map for creative idea generation	44	3.48	0.90

The results of the analysis regarding the improvement of program outcomes (PO) after two projects show that students think that teamwork skills were the most improved (M = 4.17) and communication skills were also upgraded through team activities (M = 4.02). This confirms the results from the students' reflective journals; it is natural outcome, as it is their first experience in such a format. In addition, their design ability regarding systems, elements, and processes considering practical restrictions were improved (M = 4.01) and their data analysis skills, and the planning and execution of experiments were also improved (M = 3.93). Another important point of improvement is the comprehension of engineering problems, formulation, and problem solving (M = 3.55). All of these analyses match well with the results taken from the students' reflective journals. Therefore, the experiences encountered when finding and pursuing engineering projects are considered to have changed the viewpoint of the students from being users to being makers of commercial products. In general, students thought their hard skills rather than their soft skills achieved a greater improvement.

The analysis results of difficulties encountered during the concept design are presented in Table 5. Basically students have difficulties in determining engineering problems as their project objects (M = 3.61) and feel pressure when writing reports (M = 3.45). The evaluation of the reflective journals leads to a conclusion that students encounter little difficulty in regards to team level activities at the end of the semester even though they reported that it was very difficult during the course to meditate and adjust schedules (M = 2.84). This is because students at first felt it difficult to do team work as they have no previous experience but they found many good aspects regarding team activities and described the difficulties as being of little consequence. Students acknowledged that their engineering design abilities

Table 4. The Improvement in the Program Outcomes

Items	N	Mean	Std. Deviation
PO1: The ability to apply knowledge of mathematics, basic science, engineering and information technology	43	3.49	0.64
PO2: The ability to design and conduct experiments, as well as to analyze and interpret data	43	3.93	0.60
PO3: The ability to devise a system, component, or process to meet the desired needs within realistic constraints	43	4.01	0.52
PO4: The ability to identify, formulate, and solve engineering problems	43	3.55	0.86
PO5: The ability to use techniques, skills, and engineering tools necessary for engineering practices	43	3.53	0.85
PO6: The ability to function in multi-disciplinary teams	43	4.17	0.58
PO7: The ability to communicate effectively	43	4.02	0.76
PO8: The recognition of the need for, and engaging in life-long learning	43	3.09	0.99
PO9: The broad understanding of the impact of engineering solutions in economic, environmental, and societal contexts	43	3.28	0.93
PO10: The knowledge of contemporary issues	43	3.21	0.89
PO11: The understanding of professional and ethical responsibilities	43	3.19	1.22
PO12: The understanding of other cultures and engaging in international cooperation	43	3.05	1.29
Hard skills	43	3.70	0.49
Soft skills	43	3.43	0.63

Table 5. The Difficulties Encountered in the Concept Design

Items	N	Mean	Std. Deviation
Finding design problems	44	3.61	0.95
Defining problems reflecting customer needs	44	3.30	0.95
Data collection	44	3.16	0.81
Idea generation	44	3.32	1.22
Determining the final solution	44	3.20	1.02
Team activities	44	2.84	1.27
Preparing presentations	44	3.14	1.13
Writing reports	43	3.49	1.01
General difficulties	44	3.45	0.95

had improved a great deal through their concept designs based on creative project execution (M = 3.93).

4.2 The analysis of the correlation between the instructional process and program outcome

The results for the correlation between the degree of improvement of the program outcome and the instructional process and their outcome after the class are shown in Table 6. In general the hard skills are more improved, especially in regards to patent searches in the project execution (r = 0.629, p < 0.001). The perception of engineering problems also shows a high correlation (r = 0.448, p < 0.001). In regards to the soft skills, brainstorming is the best factor in creative idea generation (r = 0.523, p < 0.001). When patent searches are used to problem solving, a high correlation is very often with program outcomes (PO1, PO2, PO4, PO5, PO7). A strong relationship with communication skills are

Table 6. The Correlation between the Instructional Process and the Program Outputs

Items	Perception of engineering problems	Patent search	Use of TRIZ	Interests in TRIZ	Brainstorming	Use of mind map	Usefulness of mind map
PO1	0.259	0.572**	0.434**	0.353*	0.258	0.401**	0.443**
PO2	0.315*	0.442**	0.406**	0.355*	0.342*	0.428**	0.302*
PO3	0.363*	0.221	0.159	0.215	0.444**	0.261	0.238
PO4	0.413**	0.491**	0.250	0.292	0.299	0.340*	0.367*
PO5	0.238	0.442**	0.143	0.058	0.010	0.153	0.054
PO6	0.155	–0.201	0.139	0.281	0.257	0.256	0.265
PO7	0.395**	0.422**	0.241	0.464**	0.461**	0.484**	0.532**
PO8	–0.004	0.321*	0.023	0.092	0.386*	0.186	0.001
PO9	0.075	0.375*	0.029	0.216	0.327*	0.190	0.200
PO10	–0.043	0.369*	0.070	0.062	0.295	0.177	0.195
PO11	–0.034	0.241	–0.077	0.011	0.346*	0.262	0.324*
PO12	–0.047	0.316*	0.134	0.157	0.342*	0.311*	0.386*
Hard skills	0.448**	0.629**	0.383*	0.346*	0.352*	0.436**	0.386*
Soft skills	0.072	0.431**	0.103	0.244	0.523**	0.398**	0.410**

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

found when applying a mind map into idea generation ($r = 0.532$, $p < 0.001$) and in the execution of the real project ($r = 0.483$, $p < 0.001$). Brainstorming is more related with communication skills as the tool most used in idea generation ($r = 0.461$, $p < 0.001$).

4.3 The effect analysis regarding individual projects

Students were requested to submit a reflective journal when making their final reports for every project. These journals are summarized in this subsection. The 1st team, the ones who attempted the 'rotating window' project, contacted the manufacturer in order to understand the industry situation and learned a great deal regarding the importance of the practical project and team activities. The 2nd team, who dealt with the 'heat problem of an air conditioner', developed a challenging project not familiar to architecture major students which showed their aggressiveness, consulted a mechanical engineering professor. They stated that they learned responsibilities as a team member and a new viewpoint regarding products used to come up with creative solutions. This was similar to 9th team's results. They developed a project regarding 'safe driving by clear view'. They visited many experts on automobile wipers; these activities provided more insights into the real issues. The 4th team, who tried to develop an 'eco friendly food leftover processor' was first embarrassed by the open-ended problem but became more confident with this real engineering process of problem solving and even confessed to falling in love with engineering. The 5th team dealt with an 'eco friendly lighting system'. They learned it was imperative not to be confined to one's own thoughts and be open to others, as their topic was a very familiar issue to daily life. The same experience was stated in the 9th team's report, as they had difficulties when they tried to solve problems with a very big frame and found the right subject in daily life finally leading to an awareness of a good attitude for solving engineering problems.

5. Conclusions and further study

In this paper, a case study of an introductory engineering design course that adopted creative design projects in which students needed to find engineering topics by themselves and solve them. The 10 teams, each with 4 ~ 5 members, covered a wide variety of projects. Although they are all in architectural engineering, the topics dealt with mechanical and environmental facets as well as with architectural ones. An analysis was made into how an engineering design course based on creative projects gives educational effects to the early stages of an engineering school. The primary result is that students get the best support by using brainstorming when dealing with innovative ideas and by patent searches when solving for perceived engineering problems. This instructional process and method turned out to be very effective in providing the basic virtues that every engineering student needs in defining program outcomes. The team activities in project fulfillment greatly influenced their team work and communication skills. Design lectures based on the creative projects were very effective in improving their design capability, data analysis, defining engineering problems, and problem solving abilities. These conclusions match well with the analysis of the correlation regarding course materials and improvements in program outcomes. A strong correlation exists regarding hard skill level improvement in program outcomes for students who gained much in their perception of engineering problems. They have the greatest difficulties in the finding of project topics, since as 3rd semester students they have no depth of experience in engineering yet. Although this course had positive effects in fostering creativity and problem solving capability, it turned out that students had difficulties in finding direction and spent much time doing trial and error procedures in order to reach an acceptable final decision for the team to resolve their problems. Several suggestions can be made to minimize these obstacles. It is better to try familiar problems with inconveniences or improvements as their goals instead of starting with big or abstract issues. The students should also be advised to consult with industry experts or to visit appropriate industrial settings in order to find and solve practical problems. In addition, it is essential to make students understand that creativity is not an inborn characteristic and can be improved by practice and self-improvement, and so therefore not to lose their motivation and confidence when obtaining their final results.

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