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An Interdisciplinary Capstone Course on Creative Product Development with Cross-College Collaboration*

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This paper presents an interdisciplinary capstone course for creative product development with cross-college collaboration in a research-intensive university. The primary focus of this course is to give undergraduate students the experience of owning their problem through finding and defining a novel and useful problem by themselves. Then, they solve the problem by creating a corresponding product as an interdisciplinary team. To accomplish this goal at Seoul National University, a teaching team was formed with cross-college faculty from the electrical, mechanical, information, industrial, and architectural engineering departments. This paper reports how to integrate this course into a research-intensive engineering college, where both students and faculty are possibly unsympathetic to or skeptical of this top-down education approach. Our assessment method is highlighted to evaluate a student's work regarding creative and interdisciplinary learning. The impact of the cultural learning context is also considered in the course. We present our findings, the lessons learned, limitations observed and recommendations with how this course extends to building a new academic makerspace at SNU.

Keywords: Capstone course; creativity education; engineering education; project-based learning; undergraduate research

1. Introduction

Scientific knowledge began to be constructed through experience and observation such as Newton's laws of motion and Kepler's laws of planetary motion. Engineering principles have been founded on scientific knowledge, on which engineering curricula have been largely based. In this context, the experiential pedagogical approach, e.g., learning-through-experience and experience-to-principle, was quite natural in engineering education, which had been identified and recommended since a hundred years ago [1].

Over the last six decades, the experiential model has met severe challenges because of demand for scientific advancements due to the Great War and the Cold War [2]. To cope with the demand, the didactic pedagogical approach – from engineering science to applications – has been adopted as the primary engineering education model [3, 4]. In the model, students are trained using fundamental and theoretical principles in their first and second years, and applications in their third and fourth years [5]. This didactic model is efficient and powerful to educate students in advanced scientific subjects within a limited time.

Despite these strengths, the didactic model has faced common problems [6–8], including:

- Low motivation: Theory-intensive education without a big picture or an imaginable application makes it difficult for students to connect what they have learned to real life. This is often the primary reason why many engineering students lose interest in and motivation during their major.
- Passive learning: Generally, the theoretical principle is not challenged during the class because engineering targets can be well described mathematically in a textbook and solutions are derived from a mathematical process. Thus, discussions and questions are less encouraged, often resulting in content reinforcement in the classroom.

In addition, the popularity of computer-aided tools has replaced hands-on experiments with computer simulations, also contributing to the problem of less-motivated engineering students [9]. These factors have resulted in a low retention rate of engineering students [10].

To overcome these limitations of the didactic model, there have been many attempts to include the experiential education approach in the engineering curriculum such as problem and project-based learning [11]. Particularly, project-based learning has attracted significant interest due to the motivation it gives to students as student experience projects from design to hands-on prototyping and testing to deployment [12]. Students can actively participate in the learning process, where the teacher's role tends to be that of an adviser or a guide, not a mere knowledge provider. Accordingly, capstone design courses for seniors [13] and cornerstone design courses for freshmen [14] have been accepted widely in engineering curricula.

To meet the needs of a multi-functional and multidisciplinary engineering environment, in addition to project-based learning, interdisciplinary

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project-based learning has been considered [15] in which a team is formed with students from different departments and colleges; sometimes, there is even crossover between engineering and non-engineering disciplines. An interdisciplinary team can provide a more realistic experience including all aspects of engineering that engineers encounter in the real workplace such as collaborating with a product planner, a designer, a marketer, and even customers [16]. Throughout this process, teaming skills, including communication, writing, persuasion, and presentation that are rarely taught in the didactic engineering education model, are highly valued.

In this paper, we share our experience of how to develop and integrate an interdisciplinary product design course into a research-intensive engineering college at Seoul National University. The primary aims of this course are as follows:

- Problem owner: Encourage students to seek and define their problem by themselves, under which the problem owner is intended to be the students,
- Completeness: Experience the whole engineering process from ideation to product planning and hands-on prototyping to even marketing,
- Diversity: Collaborate with various students and faculty from different departments, including non-engineering colleges, and
- Persuasion: Practice persuasion through team and public communication because finding a new problem entails a long period of persuasion.

Particularly, we emphasize the first aim, i.e., provision of problem owner experience to students through this course. Even in project-based learning, a problem is often bounded with a specific goal and conditions assigned by an instructor under a single discipline. In this case, students might not be the problem owner, even though students are trained and they are active in solving the given problem. To make students the problem owner, students should find and define the problem. However, it is difficult and challenging to educate students to seek and define a good problem by themselves because it is connected to a complex concept, creativity. Creativity includes not only novelty/usefulness [17] but also includes executive ability and persistence to the end, e.g., prototyping and marketing, which are not easy to cultivate in a classroom.

To accomplish these ambitious goals, this course was designed to last for two semesters with three credits per semester; the first semester focuses on developing a new product idea, i.e., defining a problem, and the second semester focuses on realizing the idea by prototyping and testing. An assessment method was developed through discussion among faculty to evaluate a student's work regarding creative and interdisciplinary learning. The target students are third – and fourth-year engineering students; however, non-engineering and second-year students can participate in the course. This interdisciplinary engineering design course started with students from design art, fashion, agriculture, medicine, and six different engineering departments. Students who took this course have received awards in several competitions. The feedback from students has been overwhelmingly positive.

In addition, we report how to integrate this course into a research-intensive engineering college, where both students and faculty are possibly unsympathetic to or skeptical of experiential engineering education [18]. Furthermore, we consider the impact of the cultural learning context in this course. Finally, this paper ends with how this experiential engineering course can help engineering students of a research-intensive engineering college and provides our lessons learned and recommendations with limitations observed. The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the course design with the rationale behind the design decisions. Section 4 provides the assessment method. Section 5 presents the course assessment results. Section 6 shares our findings, lessons learned, and our recommendations. Section 7 concludes this paper.

2. Related Works

This chapter reviews the literature on three main issues: (1) interdisciplinary product design and development courses for undergraduates, (2) creativity engineering education, and (3) cultural and pedagogical context.

There are many examples of interdisciplinary design and development courses for undergraduates. Ivins reported an interdisciplinary product design course performed with multidisciplinary project groups from interior design to ceramics in the United Kingdom [15], where students are required to produce an educational toy. Shirland and Manock reported a case study of a cross-college collaborative teaching of multidisciplinary product development, where engineering and non-engineering students and eight faculty members participated in all aspects of the course [16]. Lee and Conklin introduced an interdisciplinary undergraduate research project in electrical engineering department [19].

In the Asian context, Yung and Leung reported an integrated training program on product design for undergraduates, whose aim is to cultivate versatility in all aspects of production to adapt to a rapidly changing and export-oriented electronics industry in Hong Kong [20]. The course is designed for electronics engineering undergraduates using an experiential approach. Chang et al. reported on the development and implementation of a creative mechanical engineering design course based on the interdisciplinary approach at the National Central University, Taiwan [21]. Telenko et al. investigated a single and multidisciplinary engineering design course at the Singapore University of Technology and Design [22].

Designing a new product involves high levels of creativity. Many reports on creativity education for engineering students have studied engineering education for problem solving, idea generation, problem identification, and critical thinking [23–25]. Blicblau and Steiner reported on final year engineering student projects at Swinburne University of Technology, Australia, in the context of fostering creativity [26]. Kazerounian and Foley investigated what factors negatively affect creativity in engineering education, by suggesting ten criteria with extensive surveys [27].

Many studies have investigated the effects of culture on education and learning. The cultural difference may partly affect the comparative advantage of each culture [28]. Lynn provided a comprehensive comparison between Japan and the U.S. in engineering education in [29], where Japanese engineering education systems have emphasized teamwork more and business education less. Takahashi argued that the Japanese harmony-within-the-group culture has resulted in the situation where personnel do not show strong assertion and are not conducive to debate, which may make students less creative in engineering in [30]. Such passive learning has been commonly reported in Confucian heritage cultures [31]. Lee et al. argued that students at a top research-intensive university in Korea tend to be self-regulative and focused on getting a high grade, which was commonly observed in high-achievers in [32]. The authors pointed out that such a learning style makes students ask fewer questions. In the same context, it was reported that team project-based learning may not achieve its goal of collaborative learning if the project is approached as individual-oriented to achieve a high grade, which might provide the illusion of successful teamwork [33].

Based on the literature review, we aim at integrating the student-driven and experience-by-learning philosophy into an interdisciplinary product development capstone course for undergraduates at a research-intensive engineering college. To achieve this goal, a teaching team was voluntarily formed with cross-college faculty members from electrical, computer, mechanical, industrial, and architectural engineering, whose expertise varied from product design to ergonomics. Later, we have realized this kind of interdisciplinary courses across colleges needed a new type of academic space, e.g., makerspaces [45, 46].

3. Course Design

Fig. 1 shows our overall course design. The first semester is designed to find a good problem–a user gap and an idea–for a saleable product with a draft product design of engineering and user experience (UX). The second semester is designed to realize the idea through hands-on prototyping and UX improvement. There is no formal exam in the course. A student's grade is determined on the basis of team presentations and documentation.

3.1 First Semester

The requirements of the first semester are the following three outcomes to present a problem that students define:

- Poster and brochure
- Mockup prototype
- Presentation before faculty and engineering dean

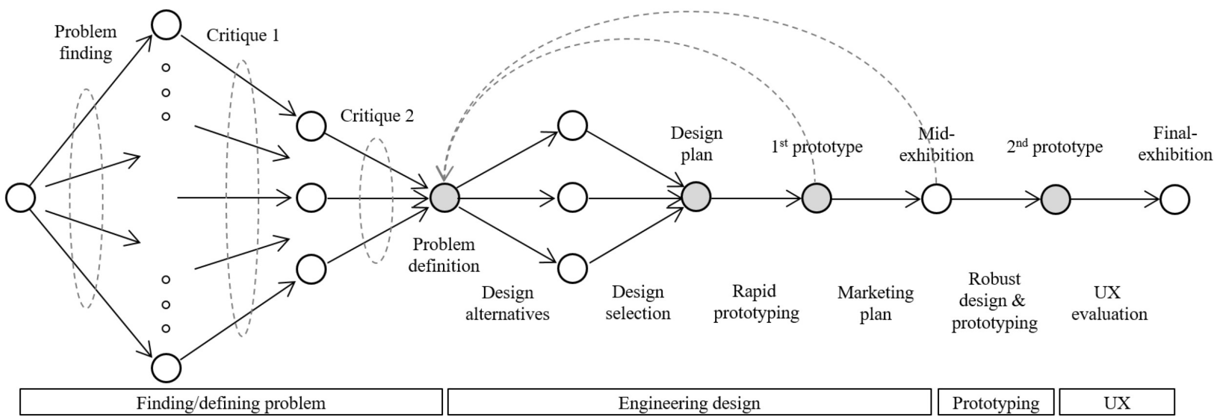

Fig. 1. Overall course architecture.

(1) Team Building: Team building is an important first and tricky part of interdisciplinary capstone courses [44]. The key principle of team building in this course is to form a team with students from different departments. Under this principle, students were allocated to a team by the teaching team at the start of the semester. To encourage students to experience an uncontrollable project environment, students were not allowed to choose which team to join.

It has been reported that a more heterogeneous team, in terms of personality [34] and gender [35], performs better in new product design and development where the task involves creativity. Our team member assignment does not consider personality; rather, the team member assignment considers gender heterogeneity.

(2) Problem Finding: The expected output of this course is a prototype product for real customers, not an engineering toy. In the first month, a series of lectures are delivered on how to find and define a user problem with a specific methodology such as brainstorming, bodystorming, lateral thinking, persona, KJ method, and design thinking.

Considering a two-semester undergraduate course, a target product is naturally bounded by low technology that can improve the inconvenience of transportation systems, the life environment, or the office environment at an early stage. This however, comes with the risk that the students will not discover a new and novel idea. In a similar context, it has been observed that students can easily develop their idea if its target customers are students themselves. However, such ideas have been possibly overlapped with other teams or prior ideas.

The teaching team has emphasized that an idea that students find should be verified by interviewing target customers. Based on experience as an instructor, meeting real customers is one of the most important ways to find a good problem. To encourage students to meet their customers, this course supports the costs of interviewing customers such as transportation fees. For example, one team changed their problem seven times through the iteration of customer meetings until the end of the first semester.

(3) Intellectual Property: Since this course is designed in the spirit of finding a new problem, lectures on intellectual property (IP) rights are provided (1) to check whether there is already an existing patent regarding their problem and (2) to secure the IP right, if there is no patent regarding this problem. Throughout this course, IP issues have been strongly emphasized to students. In the context of capstone engineering design courses, intellectual property has been approached as a potential means of recruiting company-sponsored capstone projects [36]. However, because one of the primary goals of this course is to encourage and experience problem ownership, presently, this course is designed in such a way that students retain IP ownership for projects and not the University or a sponsoring company.

(4) Engineering Design: The idea should be realized as a tangible product. For the first step toward this, the mechanical engineering faculty gives lectures on product design methodology before a team idea is fixed. Once a user gap is found, students are requested to specify user requirements quantitatively through interview and survey. Then, each team tries to find an optimal engineering solution to satisfy the requirements. To enable students to find the solution systemically, lectures are given on a concept selection process with decision matrices based on Pugh's methodology [37].

Briefly, user requirements can be categorized into a number of sub-requirements. A number of engineering solutions can satisfy each sub-requirement. Each team makes a matrix consisting of sub-requirements and the corresponding engineering solutions. Among the combination of sub-requirements and solutions, each team selects an optimal design alternative by evaluating the matrix within given conditions such as time/money cost and their expertise.

To encourage rapid prototyping, the course provides lectures on 3D printing to students. Rapid prototyping is an effective method to test and evaluate a certain engineering design alternative by making a mock-up at the early stage [38]. It activates feedback from faculty and colleges by showing an actual representation of the product. Teaching assistants are assigned to assist non-engineering students or those who have taken no engineering design courses.

(5) Marketing Plan: Each team is requested to make a marketing brochure of their product. Throughout this process, students are given the opportunity to understand and empathize with customers better, which also makes them consider how to persuade others and what aspect should be improved and redesigned. This step is generally fun and mitigates the stress from ideation to engineering design. Some teams made a promotion video even though the video was not a course requirement.

(6) Mid-Exhibition: At the end of the first semester, students must prepare an oral and a poster presentation at mid-exhibition to present (1) the problem they found, (2) an engineering product design that solves the problem, and (3) their mockup prototype in front of engineering dean, faculty, invited guests, and interested students.

3.2 Second Semester

The primary aim of the second semester of this course is to realize the idea that they proposed in the first semester. The following are the five requirements of the second semester:

- Working prototype
- Participating in a competition
- Applying for a patent
- Final presentation before venture capitalists
- Final project report

To enable students to achieve the above requirements, the following program is provided.

(1) Team Rebuilding and Prototyping: After the first semester, some teams might have to be restructured, because of, for example, team members leaving due to graduation, military duty, or personal reasons. In addition, the required expertise differs according to the team project. Thus, a new member is allowed to join the class and the team as needed.

For example, the item of one team was related to health-care. The team recruited a student from the medicine department. Another team recruited a computer engineering student to create a code for artificial intelligence. At the stage of making a prototype, an engineering skill such as designing, modeling, simulation, and analysis becomes more important, at which it was observed that senior students contributed more.

(2) User Experience Improvement: Mixing students of different backgrounds and making a marketing plan contribute to considering better UX for their product. The quality of the product can be improved systemically by a usability test. To implement the required function, capstone projects often ignore aesthetic and ergonomic design issues because students run behind schedule trying to provide aesthetic and ergonomic designs. A usability test can be performed to collect quantitative data such as time to learn, speed to use, and rate of human errors, and to gather qualitative data such as user satisfaction [39].

In this course, a one-page qualitative UX evaluation is conducted in a peer-to-peer and student-driven manner after their prototype is built. The results are provided to each team. Even with the qualitative tests, faculty and students have agreed that the UX evaluation improved the quality and completeness of their prototype greatly.

(3) Final-Exhibition: All teams have the opportunity to do a presentation for seeking funds before real venture capitalists and industrial guests. Other teams not in this course participated in the presentation. Due to the higher quality and good preparation of the interdisciplinary teams, the guest evaluators gave feedback that was more positive to the teams that took this course. Throughout some presentations during the class, students could respond to any question from the panel logically and skillfully. The proficient presentation of the students contrasts with the authors' observation from other project courses. The final exhibition demonstrates working prototypes as if students were participating in the exhibition for marketing promotion.

(4) Course Wrap-up: Students must apply for a patent and submit a final report considering feedback from the final exhibition. A lecture on patent specification is provided for better understanding of IP rights by learning through writing. In addition, a lecture on team communications is provided. Since students have experienced teaming difficulties throughout this course already, the lecture helps to organize and understand the mechanism and know-how of teaming skills based on their experiences.

4. Assessment Methods

It has been commonly reported that it is difficult to assess the capstone course because the course emphasizes creativity and hands-on experience [40, 41]. Valderrama et al. pointed out drawbacks of the conventional outcome-based assessment in a final year engineering project such as dependency on the subject criteria of the academic evaluator and not the formative assessment via one final milestone in [42]. Accordingly, the authors recommended the following: (1) establish at least three moments or milestones for assessment, (2) add peer evaluation and external experts to the assessment process, and (3) define what skills students have acquired through the project.

In accordance with the suggestions in [42], first, three moments for assessment were established for each semester: two oral presentations with the results of the prototype and one final report. Secondly, students, teaching assistants, and invited guests–a venture capitalist and former executive of engineering company and industry-university faculty–were invited to participate in the assessment. This diversity of participants aims to avoid bias from a specific and personal opinion, especially from a specific faculty member.

Lastly, we set five criteria to evaluate the work of students through discussions among faculty, which are intended to guide student learning toward the goal of this course. Table 1 presents the list of the criteria. The list is publicized to the students at the start of semester. Along with the criteria, a Likert scale of 0–5 was used to conduct the evaluation. One primary concept of the evaluation criteria is to evaluate creativity in engineering. Creativity can be defined as newness or uniqueness and value or utility [17], which is commonly identified in science, art, and politics [43]. In this course, creativity is defined as (1) to generate a novel and useful idea and (2) to realize the idea with persistence to the end. The former is divided into innovativeness, independence, and impact. The latter is divided into concreteness and interdisciplinarity.

Innovativeness is intended to evaluate the novelty or newness of a problem. This criterion often frustrates students because interviews, surveys, and feedback make them feel that there is nothing new on the earth. The teaching team guides students to overcome this frustration by exploring why they had no information on the idea or product, inconvenience that customers still experience, and deep-downing their item. For the criterion of innovativeness, a patent survey is encouraged strongly.

Independence is intended to prevent students from receiving what a customer suggests passively. We observed that industry-driven problems tend to solve a specific technological problem, where the problem is usually given in detail and is well defined by customers.

Interdisciplinarity is intended to encourage teaming activities with members of different backgrounds. Students usually tend to select an item that they have expertise on. The interdisciplinarity criterion tends to guide students to select an item and a problem solving approach so that all team members can contribute evenly to their project along with the expertise of each member.

One goal of the course is to implement a prototype within two semesters. The concreteness criterion is intended to check whether (1) the idea and design is specific enough to be implemented, and (2) the design and prototyping plan can be finished within the deadline. In this context, this criterion also covers feasibility. Lastly, the impact criterion evaluates how important or useful the end product is.

It is noteworthy that it is very difficult to evaluate concreteness and impact. The possibility of finishing a project is highly dependent on the passion, commitment, and teamwork of students. Indeed, several teams succeeded in realizing a prototype product despite their low score in concreteness at the first semester. Preference, personality, expertise, and generation would easily bias the impact. For example, the majority of students and evaluators are male, and they have not empathized with female-related issues.

Each team is required to achieve their intended outcomes while satisfying the criteria. Particularly, all final reports submitted are a hundred pages and have copious content, which are outstanding in comparison with other project reports based on the authors' experiences. Some teams made a promotion video, which was creative and fun and made their idea more persuasive.

5. Assessment Results

5.1 Project Evaluation

To evaluate the effectiveness of the instructional strategy of this course, assessment data is generated during the course. In the first semester, projects of students are graded based on three presentations, where two presentations are graded using the grading rubrics shown in Table 1. The last presentation in the mid-exhibition is evaluated by giving a total score (ranged 0–100) to each team, for enabling invited guests to join in the evaluation easily. The second semester evaluation comprises two presentations and a final report. The two presentations are graded using Table 1.

Table 2 shows the project evaluation results of spring and fall semester, where the first and second evaluations were performed in the first semester, and the rest of evaluations were performed in the second semester. Overall student performance increased during the course. The final grade is calculated from the project evaluation results, final report evaluation, and participation.

5.2 Achievements in External Competitions

Some teams in this course received awards in several competitions, including nationwide capstone design festivals, appropriate technology competitions, and student startup challenges. Some of them received air tickets for inter-national exhibition tours, which might become a motivating factor in this course.

5.3 Student Perception of Teaching

A survey was administered to all students to collect their opinions on this course using a Likert scale of 1–5 (1: strongly disagree, 5: strongly agree), as presented in Table 3. Overall, student feedback on

Table 1. Project evaluation criteria

Assessment area	Assessment Criteria
Innovativeness	Is there already a solution for the project?
Independence	Is the project the result of uniform opinions from users?
Interdisciplinarity	Does the project reflect an interdisciplinary aspect?
Concreteness	Is the design and plan of the students specific enough to be implemented? Is the product of the students realistic and feasible?
Impact	Can the project have an important impact on the real world?

Table 2. Project evaluation results (0–5)

	1st eval.	2nd eval.	3rd eval.	4th eval.
Innovativeness	3.60	3.94	4.53	4.41
Independence	3.79	4.21	4.52	4.82
Interdisciplinarity	3.98	4.39	4.55	4.70
Concreteness	3.73	4.14	4.49	4.70
Impact	3.82	3.98	4.49	4.29
Total	3.79	4.13	4.51	4.59

Table 3. Student evaluation of this course

Question	This course	College	University
Was this lecture generally satisfactory?	4.71	4.11	4.19
Were the preparations and the contents adequate?	4.43	4.17	4.23
Was the teaching method effective?	4.57	4.02	4.09
Did the lecturer proceed faithfully w/o cancellation?	4.71	4.24	4.24
Did this lecture help me enhance my capabilities?	4.57	4.22	4.22

this course is overwhelmingly positive. All the criteria exceeded average in comparison to feedback concerning projects of the college and University.

Some students confessed that this course was the first course that gave them a valuable opportunity to be able to see a big picture of engineering. Before taking this course, most students had studied engineering science as lectured in a didactic manner. This course enabled the students to connect what they have learned to the real world, which would motivate why they do engineering.

Another aspect that students liked is the close collaboration with students and faculty members from different departments. At an early stage of this course, students were surprised at the difference in each perspective and approach depending on their background. Some students mentioned that this course let them have their own story by physically realizing their idea with various colleagues from scratch.

Some aspects of the course on which the students provided feedback need to be improved. Students would give their opinions more if faculty members sat with or near students when giving feedback or evaluating projects, instead of separately sitting on the panel. Some students confessed they had difficulty following the experiential learning of requiring teaming skills and the resolving of ambiguity at an early stage because they were already accustomed to solving a specific problem assigned in the didactic education model.

5.4 Faculty Feedback

All the faculty members agreed that this course was different from conventional engineering courses regarding interdisciplinarity, student satisfaction, high student involvement, and achievement. However, this kind of course inherently requires more time commitment than the conventional education does. To resolve ambiguity during ideation, find an optimal design, and make a persuasion strategy, face-to-face meetings and discussions are effective but are a big burden to faculty at the same time.

One faculty pointed out that a non-tenured faculty might be concerned with the degradation of their research performance if the faculty is supposed to participate as an instructor in this kind of course. The democratic aspects of the interdisciplinary course can make it difficult for the faculty and staff to take ownership of the course. Furthermore, voluntary commitment is not sustainable for the educational overhead. For these reasons, despite ample evidence regarding positive effect of the course, it is difficult to sustain this kind of course. A designated faculty member can be considered as a coordinator and lead instructor to sustain this kind of course as suggested in [16, 18].

Since science-intensive engineering faculty prefers the traditional lecture style, it is difficult for the entire engineering department to accept this kind of education. Ironically, many science-intensive engineering students were very satisfied with this course because of the above-mentioned reasons in Sec. 5.3. After getting a big picture teaming experience, and meeting real world challenges through this course, it has been observed that they are strongly motivated to study for their majors. In addition, faculty members agreed that several capabilities could be acquired through this course, e.g., problem hunting, real world involvement in problem solving, hands-on implementation and persuasion by writing and presentation, will help the students to do their research as graduate students in the finest research universities.

The academic results, the faculty feedback, the student feedback, and achievements, show that students have acquired the following skills and abilities: (1) finding/defining a problem (Problem owner), (2) solving the problem by realizing the corresponding solution (Completeness), (3) collaborating with different background colleagues (Diversity), and 4) communicating as a professional through writing and presentation (Persuasion), as addressed in Section I. Table 1 is the assessment tool to evaluate how much the expectations are achieved through this course. Table 3 shows that the instructional strategy improves the abilities of the students.

6. Lessons Learned, Limitation and Recommendation

In this section, we report the lessons learned from the course together with limitations observed and our recommendations. Students have different expectations of this course: To attract students beyond a single engineering discipline, emails were sent to undergraduate students regarding the aim of this course and contents. The expectations of students and the purposes for which students registered for this course can be categorized into the following:

- Make a hands-on product as an engineering student,
- Take a course that is different from traditional lectures,
- Form a network with students studying for different majors,
- Do a project in close collaboration with faculty members, and
- Consider a startup or experience a pre-startup.

Moreover, the learning style is also very different. According to their expectations and learning styles, to understand each other intensive discussions among faculty and students is necessary, and these discussions are important to minimize the negative impact of different expectations of team members and to enhance team bonding and team performance.

Interdisciplinarity, gender-diversity, and cross-college participation should be handled carefully: Team member diversity can definitely affect the project results. Compared to PBL courses with engineering students only, students from the design arts and the liberal arts can lead their team to more user-friendly results in terms of aesthetics and story-telling. It was observed that gender diversity had positive effects on the asymmetry between male-biased engineering and a gender balanced society.

However, at the same time, the negative aspects of diversity should be considered carefully. It was often observed that idea consensus is difficult to achieve among different disciplines, whose tendency becomes obvious according to the higher orthogonality of their expertise. It was also observed that emotional differences between genders can affect team performance negatively. As an immune-suppressor, the teaching team organized dinner parties throughout this course, which students pointed out as one of the critical aspects that enabled them to finish their project successfully and that triggered the positive effects of interdisciplinarity.

Ideas are similar without any guidance: Idea brainstorming without any constraint often results in the usual inconveniences that students experience in their daily lives such as a bus, a train, an umbrella, a one-time purpose cup, a cell phone battery charger, or sleep quality issues. These ideas are found in almost every year of study and in every university. The first challenge this course faced is how to guide students not to overlap with prior ideas.

For this purpose, students were encouraged (1) to survey the market and newly emerging trends, (2) to survey a patent sufficiently, and (3) to interview target customers who are both users and decision-makers to purchase the product. Although there is no perfect and shortcut answer, the second guideline obviously works at least to avoid an overlapping problem and the last guideline helps to find a new problem based upon the experience of the students. The customer interviews enable students to get vivid feedback and a new perspective toward the problem. The frequency of customer interviews is definitely related to the project result.

Idea evaluation should be balanced: There would be no bad idea. Particularly, the feasibility of an idea is difficult to judge at an early stage. If all team members like the idea and have passion, the idea could be realized even if students have to work sometimes throughout the night. However, to guide normal students to finish their project within the time boundary of this course, specific criteria and comments are necessary.

Feedback and comments from faculty members highly affect student participation, activity, and creativity. To protect students from becoming biased towards a specific opinion and preference of a faculty member or a team leader, idea evaluation should be distributed among students, guest faculty members of industry-university collaboration, and venture capitalists. All comments and scores are shared with all students under anonymity.

The commitment of students to teamwork should be guided systemically: This course requires additional time commitment in addition to official lectures and activities in the classroom. Therefore, a team member who considers this course as less important than the other courses of that team member can degrade the overall team performance. However, the team members may be loosely connected with each other at an early stage because they come from different areas and might be complete strangers. Moreover, this course is not a mandatory course for graduation, which can make it often difficult to involve less passionate team members actively in a voluntary manner. A project-based course may commonly face this problem. One student suggested officially allocating a specific time, not in-class time, for team activity.

Face-to-face meetings with faculty is one of the key factors that affect results: The number of face-to-face meetings between students and faculty affects the results significantly. The authority of faculty is a primary reason that prevents students from discussing issues with faculty. To mitigate the effect, this course was designed to include external guests and even students in the evaluation. Students were surprised that each panel had a different opinion on some issues but a uniform opinion on other issues during their idea and design presentations. Students confessed that this breaking down of the wall between disciplines is one of the greatest experiences during the course.

Problem ownership accompanies a long persuasion process: A new problem inherently faces criticism and skepticism. To cope with criticism and skepticism, students should collect evidence, meet customers, think through the rationale, write documents, and do presentations, which are all processes of persuasion. This process helped students to be not embarrassed by any question. The process is somewhat similar to the situation that a graduate student usually faces. Moreover, a student-driven problem cultivates self-learning and lifelong learning skills. Faculty members agreed that the skills are essential to survive in a research-intensive graduate school.

Several limitations and improvements were also identified. The experience of running cross-college interdisciplinary capstone course concludes the needs of (1) a new type of academic space that can embrace more diverse experiential activities such as an academic makerspace [44], and (2) hierarchical curriculum designed to enable students to take the courses regardless of their major considering differences in the variety and level of expertise among students [45]. We continue to study the educational effect of space and curriculum in engineering education.

7. Conclusions

In this paper, we reported the cross-college collaboration to integrate an inter-disciplinary capstone course on creative product development in a research-intensive engineering school. The academic results, the faculty feedback, and the student feedback and achievements show that the teaching goals were achieved and students had opportunities for interdisciplinary teamwork, problem ownership, and defending their ideas and solutions before a panel of experts. Students who took this course have won several awards in engineering design competitions and startup competitions. Finally, the results of this work extended to building a new academic makerspace, which brought national fame to SNU, while triggering the reform of cross-college engineering education with the support of government, industry, and students.

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