World Transactions on Engineering and Technology Education
Vol.18, No.4, 2020

The effects of a capstone design course in industrial and management engineering: students' evaluation

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ABSTRACT: The capstone design course in colleges of engineering is student-centred learning based on project-based learning, and is one of the most important courses for students aiming to become competent professional engineers capable of solving real industrial problems. There have been various analyses of the educational effects of the capstone design process, but few studies have been conducted to comprehensively observe and analyse the effects of capstone design over several years, including the student, curriculum and teaching-staff perspectives. This study analyses various effects from three educational perspectives: curriculum with nine dimensions, teaching staff with three dimensions and students with four dimensions. The analysis is based on the students' evaluations of educational quality (SEEQ) collected before and after the capstone course in industrial and management engineering, from 2013 to 2019. Although there were positive effects in the three perspectives similar to the previous studies, there were differences in some dimensions that showed positive effects in each perspective. Also, some elements for improvement of the capstone course were identified.

INTRODUCTION

A number of teaching strategies and methods in higher education have been suggested to reduce the incongruence between the real world and the classroom. Among those, the capstone design course in engineering education is student-centred learning based on project-based learning (PBL), and is one of the most important courses for students. According to Bordogna, et al, the primary goals of engineering education should be to develop students' capabilities to integrate, analyse, innovate, synthesise and understand contextually individual components [1]. Thus, the objective of capstone design is to infuse a practical experience into a theory-based undergraduate engineering curriculum. Many benefits for student learning are claimed for project-based learning courses like capstone design, including:

- experience and development of teamwork;
- self-motivation and student ownership of the problem, solution and learning;
- development of self-regulation, agency, commitment and competence;
- experience in problem solving and the design process;
- exposure to the multi-disciplinary and systems nature of engineering problems;
- experience of authentic engineering problems and professional practices;
- development of reflective skills;
- development of written, oral and other communication skills;
- coping with incomplete and imprecise information [2].

While it is easy to understand that the PBL-based capstone course has the various advantages mentioned above, surprisingly, there are not many studies that quantitatively analyse such effects from the perspective of students over a long period of time. This study examines various effects from three educational perspectives of the student with four dimensions; course curriculum with nine dimensions; and teaching staff with three dimensions. This examination is based on the students' evaluations of educational quality (SEEQ) questionnaire collected before and after the capstone course in industrial and management engineering (IME) from 2013 to 2019 at Hankuk University of Foreign Studies (HUFS) in Yongin City, Republic of Korea.

STUDENTS' EXPECTATION OF THE IME CAPSTONE DESIGN COURSE

In general, the capstone courses in colleges of engineering last for one or two semesters in the fourth year. In the case of the IME Department at HUFS in Korea, such a course, as a gate to graduation, has been provided for fourth-year students since 1996 during the spring semester, and is worth five academic points. The students taking this course select their teams and projects autonomously. Usually, the teams comprise three to five members. Although the projects are based on real problems, they come in diverse types: projects formulated by students themselves from the needs of the industrial sector, proposed by faculty members from their private or public R&D contract projects, arising from the needs of the engineering school, based on the subjects of competitive exhibitions held by outside institutions, etc. Among them, projects concerned with actual industrial issues are usually recommended to students. The IME capstone design course may be distinguished into three types: the pre-course, class-course and post-course [3][4].

In the pre-course to be carried out before the semester, several activities are carried out to build up teams such as team organisation, searching for a project and a preliminary study associated with the project [5]. Furthermore, in this period student teams can consult faculty members and access the Web-based project management system for searching the existing capstone project results and references [6]. The main work in the pre-course is to prepare the proposal and presentation in the first week of the class-course.

The class-course begins with oral presentations and submitting proposals by all teams to the IME Department on Saturday of the 1st week. During the midterm evaluation of oral presentations and interim reports, it is decided to continue or stop on Saturday of the 8th week, and during the final term evaluation of oral presentations and final reports, it is decided to pass or fail the team projects on Saturday of the 16th week. The formal project execution is initiated upon the appointment of a dedicated faculty member to each project team, i.e. the advisor-to-team is appointed and the final subject of each project is determined.

The department has usually assigned a professor as an advisor to one or two project teams for 16 weeks. During the semester, each project team must provide a biweekly presentation of their project's progress in the class and the informal project activities are facilitated by weekly meetings with the advisor-to-team. Further, through frequent visits to, and meetings with industrial clients, the project team can learn about real industrial issues and explore various methods of coping with such issues. The outcomes of the project team's activities are assessed during the final presentation; all project teams must submit final reports and project outcomes (prototypes, programs, information systems, business models, results of analysis, etc). The academic score of each project team and members thereof (students) is determined by assessing three evaluations, peer review, company feedback, including comments on the quality of the project output, as well as the advisors' opinions, etc.

A departmental support system has been established for the post-course application or exploitation of each project's outcomes after the completion of the capstone course. Thus, various applications of project outcomes, such as subscribing to external competitions, patent applications, contributions to journals, software registration or the industrialisation of developed or established technologies have been encouraged by providing pertinent information, expenses and labour resources, etc. Teams usually carry out such activities autonomously during the summer vacation after the course completion.

From 2011 to 2019, on average 48 senior students enrolled in capstone classes and 11 project teams were created. While the average pass rate for the capstone course is about 70%, the failure rate is about 30%, which is not deemed sucessful. However, most students who have gone through the capstone design course mentioned that they had gained or experienced the advantages of the PBL mentioned above. In particular, they pointed out that the experience in dealing with real industrial problems and solving them through the team's collaborative effort was the greatest benefit as they gained confidence for future work after graduation. In addition to the educational effects of the capstone design of the IME Department, diverse external outcomes have also been achieved. Top prizes in various external project contests, and several articles in international conferences and referred journals are good examples. Among achievements arising from the technical results of the capstone design course are patent applications or program registrations as demonstrated on the University's Web site (ime.hufs.ac.kr/).

Since enrolling in the IME, students have been told many stories from professors and seniors about the various benefits and hardships of the capstone design course [4-6]. In such an atmosphere, students begin to prepare for capstone design through the department curriculum. At the end of the third year, they fully recognise the entire process and past achievements of the capstone course through an official orientation period and their familiarisation with the department, and look forward to the many benefits mentioned in the introductory section. However, while students have certain expectations for the educational effect of capstone design, they also have anxiety about whether they will succeed.

RESEARCH METHODOLOGY AND DATA

SEEQ and Methodology

Because the teaching and learning effectiveness of an education course is by nature multifaceted, implying the multidimensionality of students' evaluations, it is important to choose appropriate dimensions that are to be carefully examined [7]. Having reviewed a number of previous studies and evaluation schemes, the students' evaluations of educational quality (SEEQ) questionnaire, used in numerous subsequent theoretical and empirical studies [8-14], appears to be suitable for a comprehensive assessment over several years, including the student, curriculum and teaching staff perspectives of the capstone course.

According to Marsh, the SEEQ demonstrated that student ratings are clearly multidimensional, quite reliable, reasonably valid, relatively uncontaminated by many variables often seen as sources of potential bias, and are viewed as useful by students, faculty and administrators [15]. The SEEQ had originally nine dimensions to evaluate courses of diverse academic disciplines at graduate and undergraduate levels; learning/value with five evaluation items, enthusiasm with five items, organisation with four items, group interaction with four items, individual rapport with three items, the breath of coverage with four items, examination/grading with three items, assignments with two items and workload/difficulty with three items [16].

For this study, the author revised SEEQ dimensions to gather IME students' opinions before and after the capstone design course. The evaluation by students was divided into three educational perspectives: the capstone design curriculum, the capstone design teaching staff and the students themselves who participated in the capstone design course. The biggest difference in the revised SEEQ is that the teaching staff part and the participant part were separated from the existing SEEQ, and the questions of the relevant dimensions were surveyed to students. This is because the capstone design course has a curriculum that is different from other curricula, and because the role of teaching staff and a student's participation as a team member are important.

In terms of the curriculum perspective, nine dimensions of the existing SEEQ were used, and the total number of question items was 39 as of 2017, more than the 30 of the existing SEEQ. For the evaluation of the teaching staff perspective, a total of five question items were composed of enthusiasm, organisation and team interaction, and a total of 12 question items were composed of learning/value, enthusiasm, group interaction and an individual rapport item to evaluate students themselves. Using the revised SEEQ questionnaire, a survey was conducted at the beginning of capstone design for students enrolled in the course for seven years from 2013 to 2019, and then, the same survey was conducted again with the same questionnaire at the end of the course, i.e. a total of 14 surveys.

The revised questionnaire used a five-point Likert scale, such as 1 - strongly agree; 2 - agree; 3 - average; 4 - disagree; and 5 - strongly disagree. Additionally, the students were asked to list their previous relevant classes and to provide some population profile data, including age, student identification number, and so on. Therefore, a statistical analysis of 14 surveys for seven years enabled the examination of the differences by each question item, dimension and perspective before and after the capstone design course.

As mentioned above, IME students recognise the various effects and difficulties of the capstone design course before taking the course, and expect positive educational effects. Therefore, most students generally give positive evaluations on the three perspectives of the course. However, through continuous interactions between the student team and teaching staff, interactions between team members within the team, large and small problem-solving processes and multiple evaluation processes within the teams in the course, the students' final survey provides more objective and experience-based evaluations. Therefore, it is necessary to pay attention to the interpretation of the evaluation difference between the beginning and end of the course.

The revised SEEQ at the start of the class can be interpreted as reflecting the expectations of students depending on other major courses; and at the end of the class, it can be interpreted as an evaluation result based on the students' experience in performing the capstone team projects. Therefore, if the difference between the opening and closing evaluations for each element is relatively small, it can be interpreted that the capstone design course met the students' initial expectations. On the other hand, if there are many differences, the effect is more than expected, and it indicates that it is not very close to the expectations. Therefore, some educational management intervention at the capstone course and departmental level will be necessary for this case.

Data

From 2013 to 2019, a total of 306 students took the IME capstone design course, but the number of students who responded to the survey was 315 at the beginning, and 265 at the end. In general, the reason for the smaller number of respondents at the end of the class was due to students dropping out of the course in the case of teams that did not pass the midterm evaluation. On the other hand, in 2014, the number of respondents at the end of the class was greater than the number at the start of the class. It was due to responses from students in other grades. This can happen because the end-of-class survey is conducted immediately after the final evaluation is completed, and the capstone design evaluation is held as a departmental event, so students of different grades can respond.

Table 1: Number of survey respondents and the actual number of participants by year.

Year	Number of respondents at the start	Number of respondents at the end	Actual number of participants
2013	43	37	43
2014	50	54	49
2015	53	37	47
2016	58	53	55
2017	50	37	50
2018	31	21	32
2019	30	26	30
Total	315	265	306

RESULTS

Evaluation Results of Capstone Design Curriculum, Teaching Staff and Students

As shown in Tables 2 - 4, the author compared the before and after student evaluations of various educational dimensions in three perspectives. Table 2 shows paired *t*-test results of students' evaluation of the capstone design curriculum, i.e. the evaluation of students over seven years of the capstone design curriculum as the first educational perspective in nine dimensions.

Table 2: Paired *t*-test results of students' evaluation of the capstone design curriculum.

Evaluation dimension of the curriculum	Before (n = 315)		After (n = 265)		Mean difference	Significance
	Mean	SD	Mean	SD		
Learning/value	2.11	0.52	2.24	0.56	-0.12	0.007***
Enthusiasm	2.65	0.64	2.55	0.69	0.10	0.08*
Organisation of the course	2.76	0.57	2.65	0.69	0.11	0.04**
Group interaction	2.46	0.62	2.45	0.71	0.01	0.82
Individual rapport	2.62	0.83	2.42	0.85	0.20	0.04**
Breadth of coverage	2.30	0.45	2.50	0.57	-0.20	0.000***
Examination/grading	2.63	0.71	2.74	0.74	-0.11	0.06*
Assignments	4.20	0.58	3.84	0.75	0.36	0.000***
Workload/difficulty	3.84	0.62	3.68	0.62	0.16	0.002***

*p-value less than 0.10; ** p-value < 0.05; ***p-value < 0.01

The results are very diverse for each dimension. Among all dimensions, only the group interaction dimension is not statistically significant, and the other eight evaluation dimensions showed statistically significant results ranging from 1% to 10% significance level. However, the eight statistically significant evaluation dimensions also showed slightly different values. Specifically, five dimensions including enthusiasm, organisation of the course, individual rapport, assignments and workload/difficulty, resulted in smaller values than expected, but for learning/value, breadth of coverage and examination/grading, the values were larger than expected. The meaning and implications of the statistical results according to each evaluation dimension are as follows.

Group interaction evaluates whether intra-team and inter-team communication, information exchange and discussions have been actively conducted throughout the capstone course. As capstone design implies autonomously organised team-based projects, it seems to be a self-evident result that there is little difference between the high expectations at the beginning and the evaluation at the end of the course. So, the author observes that this case is related to the *experience and development of teamwork*, which is among the advantages of PBL discussed in the introduction.

Secondly, it was found that enthusiasm had a higher than expected value when evaluating, whether it improved learning motivation through the capstone design curriculum. This seems to be related to *self-motivation and student ownership of the problem, solution and learning* from the aforementioned PBL benefits. In regard to the course organisation, similar effects were obtained, which means that prior information on the curriculum was sufficient, and students were fully aware of the passing and non-passing criteria, and of curriculum management procedures. The individual rapport dimension evaluated the relationship with other students in the capstone course, and it is understood that the friendly relationship has improved considerably.

On the other hand, the assignments and workload/difficulty dimensions were expected to be considerably lower at the beginning of the course, but the tasks, task intensity and difficulty individually assigned by the team during the capstone course were found to be much greater than expected. Assignments (0.36) showed the largest difference in the average evaluation level, and workload/difficulty (0.16) showed the third largest difference. This means that students were actually experiencing the process of solving individual and group solutions to problems arising from project implementation. Thus, it seems to be an effect related to the *experience of problem solving and the design process, experience of authentic engineering problems and professional practices* and *development of self-regulation, agency, commitment and competence* of the PBL benefits.

Thirdly, the learning/value, breadth of coverage and examination/grading dimensions did not meet the initial expectations, and the difference in the mean of each dimension was statistically significant. The dimension that showed the least expected result was breadth of coverage, which was effective in terms of differentiation from other courses or the inclusion of practical content, but was far less than expected in question items, such as the utilisation of major study courses and acquisition of the latest theories. In particular, many students pointed out that knowledge in a specific major, such as computer science, is overemphasised when working on a team project, implying the necessity of using also knowledge from various majors. This finding is related to the *exposure to the multi-disciplinary and systems nature of engineering problems* in the PBL benefits, and is considered a dimension that needs to be improved in the future IME capstone design curriculum.

In relation to examination/grading, the students' evaluation indicates an expected result. In other words, three official presentation competitions, several reports and the evaluation of the final outcome give enough room for students to lower their evaluation level below the expectations for the capstone curriculum. In the case of credits, due to the relative evaluation rules, the results of the students' survey were rather poor. Therefore, it seems necessary to improve the relative evaluation rules for the capstone design curriculum.

Lastly, in relation to learning/value, the evaluation value through the curriculum was not better than the students' initial expectations. It was gauged whether the curriculum was interesting, easier than other curricula, and whether it improved the understanding of the major. The results of these question items were worse than the evaluation of the curriculum's benefits and their usefulness in the professional career. However, the level of learning/value evaluation at the beginning and end of classes shows the best results among all levels of other dimensions.

Table 3 shows the paired-*t*-test results of students' evaluation of the capstone design teaching staff for the second educational perspective. The mean differences on all the dimensions, as shown in the table, are not statistically significant. The evaluation of students on three dimensions, such as the head professor, team advisors and teaching assistants in the second educational perspective, is judged to be more than typical and continues as such from the beginning to the end of the class.

Table 3: Paired *t*-test results of students' evaluation of the capstone design teaching staff.

Evaluation dimension of teaching staff	Before (n = 315)		After (n = 265)		Mean difference	Significance
	Mean	SD	Mean	SD		
Enthusiasm	2.47	0.69	2.46	0.81	0.01	0.89
Organisation of the course	2.38	0.69	2.41	0.83	-0.03	0.64
Group interaction	2.31	0.82	2.37	0.88	-0.06	0.42

**p*-value less than 0.10; ***p*-value < 0.05; ****p*-value < 0.01

For the third educational perspective, Table 4 shows the paired *t*-test results of the peer evaluation of students who participated in the capstone design course. This evaluation is in four dimensions, showing better results in both the opening and closing classes than the corresponding dimensions in the curriculum and teaching staff. However, there is no improvement in these dimensions, while the mean difference between the beginning and end of classes for each dimension is statistically significant. It can be seen that, as Marsh mentioned, students are very honest in assessing themselves [16].

At the beginning of the class, students participated with high willingness and motivation for the project execution, but it seems that this dimension was evaluated a little weaker in the difficult project execution process. In particular, at the level of individual rapport, the results were much worse than at the start of the class in the question items of expanding friendly relationships or helping other team members. This finding has a serious implication. At the departmental level, educational measures are required to keep the original motivation and confidence of participants at least through the capstone curriculum implementation process.

Table 4: Paired *t*-test results of the peer evaluation of students who participated in the capstone design course.

Evaluation dimension of students (peer evaluation)	Before (n = 315)		After (n = 265)		Mean difference	Significance
	Mean	SD	Mean	SD		
Learning/value	2.13	0.65	2.20	0.73	-0.07	0.20
Enthusiasm	1.97	0.63	1.90	0.61	0.08	0.15
Group interaction	2.17	0.64	2.21	0.66	-0.04	0.43
Individual rapport	2.08	0.65	2.37	1.23	-0.29	0.001***

**p*-value less than 0.10; ***p*-value < 0.05; ****p*-value < 0.01

Evaluation Results of Capstone Design in Three Perspectives

The author summarises and compares the before and after the design course results of students' evaluations in each perspective of education in Table 5.

Table 5: Paired *t*-test results of students' evaluation in three perspectives of the capstone design course.

Evaluation dimension of capstone design	Before (n = 315)		After (n = 265)		Mean difference	Significance
	Mean	SD	Mean	SD		
Curriculum	2.84	0.39	2.77	0.46	0.07	0.10*
Teaching staff	2.39	0.65	2.42	0.75	-0.03	0.62
Students' peer evaluation	2.09	0.51	2.17	0.62	-0.08	0.08*

**p*-value less than 0.10; ***p*-value < 0.05; ****p*-value < 0.01

The expected level of students' expectations for the capstone design teaching staff at the beginning of the course did not meet the expectations during the course, but was not statistically significant and the average difference was very small. On the other hand, the evaluation of students who participated in the course was statistically significant as they passed through the course, showing results that did not meet the original expectations.

Although the peer evaluation of students is better in the other two educational perspectives, it seems that there is a need for educational measures to maintain or improve students' peer evaluation as aforementioned; and students' evaluations of the curriculum perspective in the capstone course are showing statistically significant improvement. However, in the analysis of differences for each dimension of the curriculum perspective, such improvement effects are largely influenced by assignments, individual rapport, workload/difficulty and the organisation of the course, so it can be said that the capstone course effectiveness is largely due to the characteristics of team-based project execution. Nevertheless, in order to further improve the effectiveness of the capstone course, feasible alternatives to learning/value and breadth of coverage are required within the department.

CONCLUDING REMARKS

PBL courses have been studied and implemented in the real world of education for decades, especially in engineering education, thanks to the benefits of teaching and learning to students. The capstone design course, based the PBL pedagogical approach, is an essential course in engineering schools, and is recognised for various educational advantages, including facilitating the transformation of students into professional engineers. However, there does not seem to be much research in a specific discipline, over a long period of time, to observe and analyse the effects of capstone design courses from several perspectives such as curriculum, teaching staff and participants.

This study examined various effects from the three educational perspectives of curriculum with nine dimensions, teaching staff with three dimensions and students with four dimensions, through surveys based on the revised SEEQ questionnaire. The surveys were conducted over seven years from 2013 to 2019, at the beginning and end of a capstone design course for IME students. Although some positive effects in the three examined perspectives were similar to findings from previous studies, the author has also identified different effects in some dimensions that showed as positive in each perspective.

Above all, among the three educational perspectives, the IME capstone design curriculum showed the strongest positive effect. In particular, among the nine dimensions of the curriculum perspective, this is due to the positive effects of five dimensions: enthusiasm, organisation of the course, individual rapport, assignments and workload/difficulty. On the other hand, however, the education perspective has shown some negative effects which needs to be improved as seen in the evaluation of the participating students (peer evaluation). Among the four dimensions of the students' perspective, the alarming effect of the individual rapport dimension needs to be improved most urgently in the IME capstone design course.

Since the launch of the IME capstone design course in 1996, it has been positioned as a department-specific culture [4]. In order to provide better PBL benefits for students in the course, the departmental efforts and faculty commitment to students' self-engagement and motivation in the process of the capstone course are critically important. In addition to this research on various factors affecting the educational effect of the capstone course, further research is needed on the factors affecting the successful project execution of participating students, the effects and factors influencing employment opportunities for graduates, their employment activities, etc.

ACKNOWLEDGEMENTS

This research was supported by the Basic Science Research Programme through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (NRF-2017R1A2B4005858) and Hankuk University of Foreign Studies (HUFS) research fund of 2020.

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