Factors affecting the performance of student project teams in capstone design programmes

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ABSTRACT: This study examined several factors that affect the performance of student project teams that participated in the capstone design curriculum of industrial and management engineering for six years from 2014 to 2019, and it aimed to identify student-centred effective and efficient measures to improve team performance. The dependent variables regarding team performance in the capstone curriculum were the project team's course results (pass or fail) and the grade point average. Factors affecting the project execution were based on previous studies and included: academic achievement, multi-disciplinary ability, project subject, team size and gender ratio composition, individual initiative, communication and teamwork as independent variables. From two models, multiple factors affected team performance in different ways. Similarly to previous studies, it was found that the better the existing academic achievement and teamwork, the more positive effect on team performance, but contrary to expectations, the project team with knowledge of corporate topics or various majors was found to have a negative effect. These results are expected to serve as effective guidelines for students' team formation, project topic selection, and team execution and operation of future capstone design curricula.

Keywords: Capstone design, student performance, performance factor, industrial and management engineering, logistic regression, multiple regression

INTRODUCTION

In order to meet societal needs for competent practitioners who will be ready for the multifaceted challenges of rapid advancement of technology as well as changes in the global economy, the paradigm of college education has been changing, especially in engineering schools. Recently, industrial practices usually require that students who majored in engineering disciplines be equipped not only with knowledge of their major, but also have other competencies, such as communication skills, collaborative capability, teamwork skills, systematic thought and leadership, as well as an understanding of business issues associated with legal or environmental concerns [1]. The capstone design of engineering schools seeks to prepare engineering students for work in industry by challenging teams to synthesise solutions to open-ended, real-world problems, typically through the employment of project-based learning activities constructed from industrial problems [2].

In most engineering schools, therefore, the capstone course has been offered to senior students as a gateway to achieving their academic degree. Typically, in one or two semesters of the course, teams define a problem, plan their approach, propose creative solutions, analyse the proposed solutions, produce or implement the solutions, and then communicate them internally and externally. Participation in capstone design provides students with the opportunity to transition from student communities of practice to professional communities of practices, i.e. from classroom to real industry.

Working with a client-advisor from the field (industrial engineers, start-up companies, company representatives, teaching staffs, laboratories, etc) in a type of apprenticeship, students are challenged with real-world needs. While the students in the capstone course are not full members in the professional community, contextualising the problems, needs or services within the field's practices provides them with the opportunity for situated learning and affords them the opportunity to apply their knowledge and skills toward the development of a robust understanding of what it means to be an engineer [3]. This facilitates an identity shift from student to professional engineer [4].

There are various studies on the educational effectiveness of capstone design [5-8]. Capstone design shows various effects of the project-based learning model [8], and also shows positive effects on employment [5]. Therefore, not only instructors but also learners have recognised the importance of the capstone design curriculum and have been seeking various ways to successfully function in the capstone design curriculum. In particular, research on various factors that can effectively and efficiently guide student team projects is essential for the performance of the capstone design curriculum. Accordingly, this study analysed major factors affecting the project team performance of students who participated in the capstone design

curriculum conducted from 2014 to 2019 in the Department of Industrial and Management Engineering (IME) at Hankuk University of Foreign Studies (HUFS) in Korea.

TEAM PERPORMANCE AND FACTORS

In capstone design, the performance of student team projects can be evaluated in a variety of ways. Examples include learner satisfaction with the curriculum, learning achievement and quantified grades [9]. When analysing the performance of various educational programmes or methods, satisfaction and learning achievement are set as main performance factors [10-12]. However, on the other hand, there are many studies that use the grades obtained by students as learning outcomes [13-15]. Although there are limitations in using grades as a proxy variable for curriculum achievement, there is an advantage in that a wide range of past grade data can be used for analysis.

In this study, as a result of analysis based on six years of data, the credits earned by students were used as a team performance variable in capstone design. Also, unlike other curricula, in capstone design, projects are carried out in teams, the results are presented and the results are evaluated. In many engineering schools, in addition to granting credit to students, student teams are evaluated as passing if their team project results exceed a certain level established by faculty members and/or outside experts. Otherwise, their teams will be evaluated as failed, and the passing team will be eligible to graduate or participate in external competitions [16]. In this study, pass/fail was also used as a proxy variable for team project performance in capstone design.

There are many factors that influence student team performance in capstone design. First, students' grades from the first to the third year are an important influencing factor. Several existing studies have shown that the higher the team's grade point average (GPA), the more effectively the project is carried out [17]. This is because the higher the grade, the higher the understanding of major knowledge, and it can also be an objective indicator of the sincerity and responsibility required in the collaborative learning process.

Next, the number of team members can be an important factor affecting team performance. As the number of team members increases, social loafing within the team increases and a free-riding phenomenon may occur, which can have a negative effect on team performance [18][19]. Conversely, if the number of team members is too small, the work load may increase and project goals may not be achieved. Typically, the number of team members in capstone design consists of two to five people, and the appropriate size and scope of the project are set depending on the size.

The third factor is the level of communication within the team. Communication between team members has a direct impact on project performance. Students who have bigger difficulty in communication seem to have greater difficulty performing project tasks [20]. Typically, the level of communication within a team is measured through surveys.

The fourth factor is teamwork, which is similar to communication within the team, but is a factor that demonstrates more comprehensive collaborative learning capabilities. Since capstone design is a team project based on co-operative learning, it has been shown that the higher the teamwork ability, the better the performance of learners [21]. The level of teamwork is also usually measured through student surveys.

The fifth factor is the gender ratio of male and female students on the team. Gender diversity within the team strengthens the group process of co-operative learning, which is an important factor in team productivity [22]. As the proportion of female students increases in engineering schools, gender diversity in team learning is expected to have a significant impact on team performance.

Capstone design project performance is a series of problem-solving processes in which learners identify problems and analyse causes, and how actively they participate in this process is an important factor in the successful performance of the project [23]. Therefore, team members' proactivity in the project can be an important team success factor. Currently, many universities encourage students to take double majors or multiple majors in various majors in addition to their main major. As the need for talented individuals with multidisciplinary knowledge capabilities emerges to solve various social and industrial problems, many universities are establishing systems to offer multiple majors. In particular, when carrying out team-based projects, it is reported that teams with knowledge from a variety of majors have better problem-solving abilities than teams with knowledge from a single major [5].

The final factor considered in this study that can affect team performance relates to the project target/topic. Looking at the experience of delivering the capstone design curriculum in the Department of IME at HUFS over the past 20 years, approximately 80% of the total topics have been industrial topics related to actual corporate issues, and the remainder to non-industry topics, such as research papers [16]. Therefore, it is believed that the characteristics of the project topic can affect team performance.

In summary, in this study, whether or not the project team passed (Cap_P/F) and the final grade awarded to the team (Cap_G) were set as dependent variables in the capstone design team performance, and the following factors affecting the dependent variables were assumed as independent variables: earned credits (GPA), number of team members (Size), communication level within the team (Commu.), teamwork (TeamW), gender ratio (G_ratio), proactiveness (Proact.), multidisciplinarity (M_Disp.) and project target (Target). Considering the above eight independent variables and two dependent

variables, main factors affecting the performance of the project team in the capstone design were examined through casual analysis, and educational implications presented for more effective operation of the capstone design curriculum.

METHODOLOGY AND DATA

Model

In this study, two causal analysis models were established under the assumption that eight factors being independent variables affect two dependent variables, which were the performance outcome variables of the student project team. In the first model, a logistic regression was applied because the evaluation of the student team project was a binary variable, pass or fail. The general model of logistic regression analysis for various independent variables that affect a binary dependent variable is expressed as follows [24]:

$$\text{logit} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \tag{1}$$

Here: logit = logOdds = log(p/(1-p)), and the success probability of the project team is expressed as p = Pr(Y = 1/all X).

In the estimation of a logistic regression equation, if the regression coefficient is greater than 0, the odds ratio is greater than 1, and if the regression coefficient is less than 0, the odds ratio is less than 1. If the odds ratio for a specific independent variable is greater than 1, it means that if the independent variable increases by one unit, the odds ratio or the likelihood of passing the capstone design, increases. Conversely, if the odds ratio for a specific independent variable is less than 1, it means that increasing the independent variable by one unit will decrease the odds ratio, i.e, the passing possibility.

Also, regardless of whether the team passes or not, each student is given credit for the capstone design course. Typically, a team that passes receives a higher grade than a team that does not pass, but it is given in consideration of the creativity and sincerity shown by each student in the capstone design curriculum. Therefore, the second model, in which grades are set as the outcome variable of team performance, is a multiple regression analysis that models the linear relationship between independent variables and a dependent variable, and is expressed as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon \tag{2}$$

Data

The analysis in this study was based on a survey conducted annually for 202 fourth-year students from 2014 to 2019 in the Department of IME and data from the undergraduate database of HUFS. The characteristics of the variables and data collection methods applied to the two analysis models are shown in Table 1 below.

Table 1: Variables and descriptive statistics.

Variable	Variable code	Min.	Max.	Mean	SD	Data source/etc.
Dependent variable	Cap_P/F	0	1	0.767	0.424	Department DB, binary variable
	Cap_G	1.0	4.5	3.645	0.867	University DB
Independent variable	GPA	2.12	4.35	3.371	0.425	University DB
	Size	2	5	4.28	0.750	Department DB
	Commu.	1.5	5.0	3.779	0.672	Annual survey
	TeamW	1.0	5.0	3.728	0.854	Annual survey
	G-Ratio	0	1.0	0.365	0.277	Department DB
	Proact.	1.25	5.00	3.999	0.614	Annual survey
	M_Disp.	1	4	2.180	0.926	University DB
	Target	0	1	0.535	0.500	Department DB, binary variable

Among the eight independent variables that affect team performance shown in Table 1, three variables, communication level, teamwork level and proactiveness, were measured and collected from a comprehensive student survey based on the revised students' evaluations of educational quality (SEEQ) questionnaire [8] conducted every year at the end of the capstone design curriculum. In order to measure the level of communication of individual students, the following two questions were asked: *Do you think you actively participated in communication with instructors in the capstone design? Do you think you actively participated in communication with other team members in the capstone design?* It was measured using the average value of the 5-point Likert response values for the above questions. The teamwork level was also measured as the average value of the responses to the following two questions: *Do you think you actively participated in knowledge exchange and discussion in the capstone design?* and *Do you think you maintained or expanded close relationships with other students in the capstone design?*

The proactiveness of individual students was similarly measured as the average of the responses to the following four questions: *As a participant in the capstone design, do you think you were enthusiastic about learning? Do you think you*

actively performed your position within the team, such as team leader or secretary of the capstone design? Do you think you actively asked for help or advice about your problems from professors or other students when carrying out the project? and *Do you think you actively and actively participated in the team activities of the capstone design?*

From the past capstone design data stored in the department office, the authors of this article collected the number of team members, team gender ratio as proportion of female students on the team, whether the corporate topic was the target of the student team project, and the dependent variable, whether or not each team passed. In particular, the average of whether or not the capstone design team passed was 0.767 (Table 1), which indicates that the percentage of team members who passed among students who took the capstone design curriculum for six years was 76.7%.

Additionally, the authors collected the GPA of students up to their third year, capstone design grades, and the multidisciplinary variables of students who participated in capstone design from the university database. In particular, the level of multidisciplinarity measures - how diverse the academic base within a team is - was measured by the number of double majors of individual students within the team. For example, if a team of five includes two IME majors, two computer engineering as a double major, and one statistics double major, the multidisciplinary level is measured as 3.

RESULTS

Factors Affecting Capstone Student Team Pass or Fail

In this study, SPSS 23.0 was used to determine the variables that affect the student team's performance variable of passing or not. The results of the logistic regression analysis are shown in Table 2 below. Table 2 shows the estimation results of model 1a, which was estimated using all eight independent variables, and model 1b, which excluded the communication variable. Since the *p* of the χ2 statistics of models 1a and 1b are both less than 0.01, it statistically shows that the coefficients of the variables are not all 0. And the *p*-value of Hosmer and Lemeshow's goodness-of-fit statistic (H-L) for models 1a and 1b is greater than 0.05, showing a good fitness.

Table 2: Logistic regression estimation for capstone pass/fail.

		Constant	GPA	Size	TeamW	G-Ratio	Proact.	M_Dis.	Target	Commu.	χ^2	H-L
Model 1a	β	-2.024	0.443**	-0.278	0.254	0.773	0.386	-0.206*	-0.393	0.406	24.52	4.733
	Exp(B)	0.071	2.709	0.634	1.424	2.685	1.188	0.701	0.589	1.296	(*p*=0.002)	(*p*=0.786)
Model 1b	β	-2.025	0.440**	-0.277	0.229*	0.753	0.306	-0.204*	-0.394		24.11	7.472
	Exp(B)	0.070	2.784	0.639	1.526	2.461	1.383	0.712	0.593		(*p*=0.001)	(*p*=0.487)

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

From the results of the logistic model analysis, the factors that have a statistically significant impact on whether a student team passes or not are GPA and multidisciplinarity (M_Dis.). In the second logistic model analysed that excluded the communication level, teamwork (TeamW) was found to be a statistically significant influencing factor in addition to the previous two factors. The analysis of the main influencing factors on the student team's performance based on the second model is as follows.

It was found that students' GPA up to their third year had the greatest positive effect on passing the capstone design curriculum, which is believed to be a very natural result similar to many existing studies. The second factor that has a positive influence is teamwork. In the capstone design curriculum, teams voluntarily formed by students carry out freely selected project topics based on co-operative learning process, so teamwork is expected to have a positive influence on project performance. However, contrary to the authors' expectation, multidisciplinarity was found to have a negative effect on project performance. This seems to be due to the fact that this study defined multidisciplinarity simply as the number of double major students in the team, rather than as multidisciplinary knowledge or abilities that can have a positive effect on project performance as in previous studies [5]. In particular, in the process of solving project problems, there is a significant number of students who choose to double major in humanities or social sciences, which is somewhat distant from the basic knowledge and skills for direct solutions.

Although not statistically significant, some interesting facts can be found when looking at the impact of other factors on the capstone design performance. First of all, the larger the number of team members (Size), the less likely the team is to pass. This can be explained in connection to teamwork. The more students there are on a team, the more likely it is to reduce teamwork, and the experience of department professors who have guided teams shows that conflicts in a team are a major factor in team failure [16]. And in terms of the team's gender ratio (G-Ratio), the greater the proportion of female students, the greater the likelihood of passing the capstone project. In addition, the chances of passing projects targeting companies (Target) are decreasing. This appears to be a statistically significant factor in the multivariate regression analysis for capstone design grades.

Factors Affecting Students' Capstone Grades

The results of the multivariate regression analysis, also using SPSS 23.0, with students' capstone design curriculum grades as the performance variable are shown in Table 3 below. As with the logistic regression analysis, Table 3 shows

the estimation results of model 2a, which was estimated using all eight independent variables, and model 2b, which excluded the communication variable. The two F test statistics show that two multivariate regression estimations are appropriate. As shown in Table 3, four factors are identified that have a statistically significant impact on student performance including teamwork and a corporate topic of projects unlike in the logistic regression analysis.

Table 3: Multiple regression estimation for capstone grades.

		Constant	GPA	Size	TeamW	G-Ratio	Proact.	M_Dis.	Target	Commu.	Ad_R^2	F
Model 2a	β	0.068	0.485***	0.055	0.291***	0.286	0.386	-0.134**	-0.216*	0.085	0.218	7.99***
	t	0.107	3.617	0.700	3.675	1.368	1.188	-2.081	-1.792	0.668		
Model 2b	β	0.066	0.495***	0.056	0.314***	0.753	0.273	-0.131**	-0.215*		0.220	9.09***
	t	0.105	3.726	0.708	4.415	2.461	1.313	-2.036	-1.787			

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

Similar to the logistic analysis, student GPA and teamwork were identified as the most important factors that positively affected student performance. Although students form teams autonomously, ongoing education on GPA management and the importance of teamwork is required starting from the early grades. In particular, there is a need to educate students on the importance of team composition in the capstone design course orientation.

Multidisciplinarity and corporate topics, which have a statistically significant negative effect on capstone design credits, need to be interpreted more carefully. Multidisciplinarity can be judged by the results of the definition of multidisciplinarity, such as logistic analysis. However, the low grade level of students participating in corporate-themed projects is a very concerning phenomenon. This is because the purpose of capstone design is to secure qualifications as a professional engineer through the process of solving more realistic corporate problems through a team co-operative learning process. Therefore, if this phenomenon continues, students in the future will be more likely to carry out projects by forming teams with fewer team members and easier hypothetical topics rather than realistic corporate problems, which runs counter to the purpose of the capstone design curriculum.

CONCLUSIONS

Since capstone design shows various effects of the project-based learning model, not only instructors but also learners have recognised the importance of the capstone design approach and have been seeking various ways to successfully operate the curriculum. In particular, research on various factors that can effectively and efficiently operate student team projects is essential for the performance of the capstone design curriculum. The authors of this article examined key factors influencing student team performance targeting the capstone design conducted by the Department of IME, HUFS, from 2014 to 2019.

It was found that the factors that have a positive effect on capstone design performance are GPA, which indicates students' project performance ability, and teamwork, which is most necessary in the collaborative learning process for problem solving. This is the same result as presented in previous studies. However, in this study implications on two factors that have a negative effect on capstone design performance have been identified, i.e. multidisciplinarity and corporate topics.

Considering the importance of corporate topics in capstone design, close and continuous interaction with internal information and companies is necessary for students to select and carry out corporate topics. This aspect is somewhat difficult for them. Therefore, through agreements with various companies at the department or university level, there is a need to establish institutional arrangements for student project teams to select corporate topics, interact with companies, commercially utilise the results of this interaction, and to continuously expand this approach to companies in various industries.

Previous studies have showed that the multidisciplinarity of the capstone design team has a positive effect on team performance, emphasising that diverse disciplinary knowledge and methodologies are needed to solve real problems in the industry. The multidisciplinarity concept in this study appears to have been derived by simply measuring the target students' double major in the school system rather than measuring their possession of multidisciplinary knowledge and skills. It is necessary to define and measure variables that reflect the characteristics of multidisciplinarity, and this is left for future research.

This study focused on a single department and offered suggestions to improve the operation of capstone design more effectively and efficiently. Therefore, there are limits to its application to various other disciplines, but this study is expected to serve as a reference for other departments in engineering schools or disciplines that wish to introduce and operate capstone design.

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REFERENCES

1. Hackman, S., Sokol, J. and Zhou, C., An effective approach to integrated learning in capstone design. *INFORMS Trans. on Educ.*, 13, **2**, 68-82 (2013).
2. Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D. and Leifer, L.J., Engineering design thinking, teaching, and learning. *J. of Engng. Educ.*, 92, **1**, 7-25 (2005).
3. Lave, J. and Wenger, E., *Situated Learning: Legitimate Peripheral Participation.* New York: Cambridge University Press (1991).
4. Johri, A. and Olds, B.M., Situated engineering learning: bridging engineering education research and the learning science. *J. of Engng. Educ.,* 100, **1**, 151-185 (2011).
5. Hotaling, N., Fasse, B.B., Bost, B.F., Hermann C.D. and Forest, C.R., A quantitative analysis of the effects of a multidisciplinary engineering capstone design course. *J. of Engng. Educ.*, 101, **4**, 630-656 (2012).
6. Julien, B.L., Lexis, L., Schuijers, J., Samiric, T. and McDonald, S., Using capstone to develop research skills and graduate capabilities: a case study from physiology. *J. of Univ. Teaching & Learning Pract.,* 9, **3**, 1-15 (2012).
7. Chan, C.K.Y., Wong, G.C.K., Law, A.K.H., Zhang, T. and Au, F.T.K., Evidence-based conclusions concerning practice, curriculum design and curriculum reform in a civil engineering capstone design course in Hong Kong. *Inno. in Educ. & Teach. Inter.,* 54, **3**, 260-274 (2017).
8. Kim, M-S., The effects of a capstone design course in industrial and management engineering: students' evaluation. *World Trans. on Engng. and Technol. Educ.,* 18, **4**, 410-416 (2020).
9. So, H.J. and Brush, T.A., Student perceptions of collaborative learning, social presence and satisfaction in a blended learning environment: relationships and critical factors. *Comp. & Educ.*, 51, **1**, 318-336 (2008).
10. Kartha, C.P., Learning business statistics: online vs traditional. *The Busi. Rev.,* 5, **1**, 27-32 (2006).
11. Cao, Y. and Sakchutchawan, S., Online vs. traditional MBA: an empirical study of students' characteristics, course satisfaction, and overall success. *The J. of Human Res. and Adult Learning*, 7, **2**, 1-12 (2011).
12. Johnson, D. and Palmer, C.C., Comparing student assessments and perceptions of online and face-to-face versions of an introductory linguistics course. *Online Learning,* 19, **2**, 33-42 (2015).
13. Xu, D. and Jaggars, S.S., The effectiveness of distance education across Virginia's community colleges: evidence from introductory college-level math and English courses. *Educational Evalue. and Policy Analysis,* 33, **3**, 360-377 (2011).
14. Cavanaugh, J.K. and Jacquemin, S.J., A large sample comparison of grade based student learning outcomes in online vs. face-to-face courses. *Online Learning*, 19, **2** (2015).
15. Bergeler, E. and Read, M.F., Comparing learning outcomes and satisfaction of an online algebra-based physics course with a face-to-face course. *J. of Sci. Educ. and Technol.,* 30, 97-111 (2021).
16. Kim, M-S., Lessons from a capstone design course with a 3D printing project. *Global J. of Engng. Educ.,* 21, **3**, 179-188 (2019).
17. Garry, B.G., Effect of previous experience and attitudes on capstone project achievement. *Proc. 2013 ASEE Annual Conf.,* Atlanta, Georgia, 23.462.1-23.462.17 (2013).
18. Karau, S.J. and Williams, K.D., Social loafing: a meta-analytic review and theoretical integration. *J. of Person. And Soc. Psych.,* 65, 681-706 (1993).
19. Devine, D.J, Clayton, L.D., Philips, J.L., Dunford, B.B. and Melner, S.B., Teams in organizations: prevalence, characteristics, and effectiveness. *Small Group Research,* 30, 678-711 (1999).
20. Blue, A.V., Sratton, T.D., Donnelly, M.B., Nash, P.P. and Schwartz, R.W., Students' communication apprehension and its effects on PBL performance. *Medical Teacher*, 20, **3**, 217-221 (1998).
21. Joo, Y., Lim, K. and Lee, S., Project-based learning in capstone design courses for engineering students: factors affecting outcome. *Issues in Educ. Research,* 29, **1**, 123-140 (2019).
22. Bear, J.B. and Woolley, A.W., The role of gender in team collaboration and performance. *Interdisciplinary Sci. Rev.: Gender in Sci.,* 36, **2**, 146-153 (2011).
23. Park, M. and Choi, D., The effect of simulation integrated with problem based learning on system thinking, learning flow, proactivity in problem solving and performance ability for medication in nursing students. *J. of Digi. Convergence,* 16, **8**, 221-231 (2018).
24. Stoltzfus, J.C., Logistic regression: a brief primer. *Acad. Emer. Med.*, 18, **10**, 1099-1104 (2011).

BIOGRAPHIES

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