

Project-based learning in capstone design courses for engineering students: Factors affecting outcomes

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This study aimed to examine the structural relationships among factors that affect learner satisfaction and achievement in project-based learning for capstone design courses in engineering education. Specifically, problem-solving efficacy, task value, teamwork competency, and task authenticity are suggested as critical factors that affect learner satisfaction and perceived achievement. The study employed structural equation modelling in order to examine the relationships among the variables, and the data from 363 university students who were enrolled in capstone design courses were analysed. The results suggest that task value and task authenticity exerted significant effects on learner satisfaction. Problem-solving efficacy, teamwork competency, task authenticity, and satisfaction exerted significant effects on learning outcomes, but task value did not. The results imply that the effects of problem-solving efficacy on perceived achievement reveal the importance of motivational factors in capstone design courses. In addition, instructional strategies that highlight task utility value and provide environments in which learners can share that value would be meaningful in promoting learning effectiveness in capstone design courses.

Introduction

The paradigm of higher education has been changing, 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 world economy. Recently, 21st century competencies, such as communication skills, creativity, and problem-solving skills, have been more emphasised, and higher education has paid keen attention to fostering these skills in college students (Becker, Cummins, Davis, Freeman, Glesinger & Ananthanarayanan, 2017). Specifically in engineering education in South Korea, the Accreditation Board for Engineering Education of Korea (ABEEK) was launched in 1999 to address these societal changes, by adopting an accreditation system for quality assurance in engineering degree programs. A capstone design course, which is the context of this study, is one of the requirements for engineering education accreditation. In capstone design, students collaboratively perform projects that require applying prior knowledge to solve open-ended, real-world problems (Hotaling, Fasse, Bost, Hermann & Forest, 2012; Lynch, Goold & Blain, 2004; Onal, Nadler & O'Loughlin, 2017). In other words, capstone courses are designed to bring together all prior knowledge that students collected during their undergraduate coursework to work either individually or collaboratively. However, since teamwork is considered a critical competency to succeed as a professional, an increased number of capstone design courses require students to accomplish a design project in a team setting (Zhou & Pazos, 2014).

The capstone courses usually involve the attributes of project-based learning. For example, students are likely to encounter several problems while working on the given project, and also, they are expected to produce a desired end product (Savery, 2015), which echoes the definition of capstone design courses. During this student-centred learning process, students develop more in-depth and sophisticated knowledge in their respective disciplines as well as higher-order thinking skills (Chan, Wong, Law, Zhang & Au, 2017; Solnoskya, Parfitta & Holland, 2015). However in South Korea, the history of capstone design courses is relatively short, and instructors have struggled with the logistics of course implementation and strategies for facilitation, while students have experienced difficulties in problem-solving and teamwork processes (Kim & Kim, 2013; Kim & Ji, 2009). Therefore, there is a need to further investigate the design and implementation of capstone design courses to improve their effectiveness (Lee, Chun, Lee & Chang, 2009). Specifically, factors that affect the effectiveness of capstone design courses should be identified, so that educators can design them in consideration of these factors.

Reviews of prior research worldwide revealed that there are studies on instructional models and strategies for capstone design courses (Buzzetto-More, 2013; Paretto et al., 2011), including evaluation of learning outcomes (Chan et al., 2017; Julien, Lexis, Schuijers, Samiric & McDonald, 2012; Hotaling et al., 2012; Moreno et al., 2017). In South Korea, capstone design studies have mostly been simple case studies (Chung, Ha & Kim, 2011; Han & Kim, 2011), while studies of project-based learning models for engineering students, which are a basis for capstone design, have been lacking (Yoon & Lee, 2009), as are studies with a comprehensive yet analytic perspective of capstone design courses. It is thus necessary to investigate the overall learning mechanisms of capstone design courses, given that project-based learning is highly complicated and team-based. This study examined learner satisfaction and learning achievement as output variables of capstone design project-based learning. Satisfaction has been considered important, because it strongly predicts learning achievement (So & Brush, 2008). In particular, in learning environments in which learners have more control over their learning processes, satisfaction plays a more important role in their learning motivation and continuation of learning (Chaparro-Peláez et al., 2013).

In terms of predictors for the output variables, learners' problem-solving efficacy and task value were examined following the expectancy-value model (EVM). The EVM has successfully described the relationship between learners' motivation and learning outcomes, by confirming that learner achievement and achievement-related choices are likely determined by their expectations for success and their subjective task values. Because capstone design courses address real-world problems, learner problem-solving efficacy and task perceptions are likely to play an important role in their successful learning. Efficacy expectancy, as proposed by Bandura (1986), relates to beliefs about one's abilities and competence (Pajares, 1996; Plante, O'Keefe & Théoët, 2013; Wigfield & Eccles, 2000). Task value, the V in EVM, is defined as how important, useful, or enjoyable the learner perceives the task, which predicts learner performance, as well as continuation of learning (Bong, 2001; Cole, Bergin & Wittaker, 2008). In this study, task value consisted of intrinsic value, attainment value, and utility value, following the EVM. Intrinsic value refers to the level of enjoyment or interest that an individual gains from a given task or

learning experience. Attainment value indicates the level of importance of successful task performance, resulting in a link between tasks and individual identities and preferences. Utility value is the usefulness of the task to the individual's future.

In addition to the motivation factors, teamwork competency was suggested as another predictor for this study. Teamwork has also been referred to with terms such as group process (Gladstein, 1984) and team skills (Mohrman, Cohen & Mohrman, 1995). Teamwork competency is defined as knowledge, skills, and attitudes that result in effective team performance, according to Cannon-Bowers, Tannenbaum, Salas and Volpe (1995); goal setting, coordination, communication, and leadership skills are included as sub-constructs. In addition, task authenticity was added to the research model, because capstone design is rooted in a constructivist paradigm of learning. Authentic tasks are ill-structured and complex in nature, having the salient attributes of real-world problems. Because of these characteristics, authentic tasks not only facilitate deep reflection on problem solving, but also provide opportunities for designing a variety of different, creative solutions to problems. Also, prior research has reported that authentic tasks tend to promote transfer of learning (Herrington, Reeves, Oliver & Woo, 2004; Jonassen, 1991; Lai, Portolese & Jacobson, 2017).

Overall, researchers have attempted to investigate the variables that have effects on learner satisfaction and achievement in capstone design courses, and EVM has been used to justify the selection of these variables; in addition, teamwork competency and task authenticity were suggested as other predictors of successful learning in capstone design courses. Therefore, the purpose of the study was to investigate factors that affected learner satisfaction and project-based learning achievement, specifically in capstone design courses.

With this theoretical framework in mind, an extensive literature review was conducted. First, problem-solving efficacy, task value, teamwork competency, and task authenticity were identified as predictors of *learner satisfaction* in a project-based capstone design course. Problem-solving efficacy is a context-specific construct of efficacy that is based on expectancy theory. Efficacy is defined as one's belief in one's ability to accomplish a task, and in general, has been reported as a strong predictor of learner satisfaction (e.g. Liaw, 2008; Joo, Lim & Kim, 2013); in a project-based learning context, Chowdhury et al. (2002) reported that learners with high efficacy showed high satisfaction. Task value has been reported as one of the most powerful predictors of learner satisfaction in prior research on online learning environments (e.g., Artnino, 2008). Teamwork has often been studied in corporate contexts; for example, Gladstein (1984) and Hoegl and Gemuenden (2001) reported that perceived level of teamwork, such as communication and coordination, affected job satisfaction. Separately, however, Tseng and Ku (2011) reported that teamwork also predicted learner satisfaction in online distance learning. Given that most of the capstone design projects require team-oriented tasks, student teamwork competencies are likely to predict learning outcomes. Lastly, research on task authenticity has focused on instructional design models and strategies for situated learning courses (e.g., Herrington, 2005; Lebow & Wager, 1994), but few studies have investigated task authenticity as a predictor of learner satisfaction. Nicaise, Gibney and Carne (2000)

conducted a qualitative study that explored learners' experiences in project-based learning, and reported that learners who perceived the given task as being authentic showed greater learning satisfaction.

Second, problem-solving efficacy, task value, teamwork competency, task authenticity, and satisfaction were identified as predictors of *learning achievement*. Prior research on problem-solving efficacy reported that it significantly predicted learning achievement, such as GPA and test scores (e.g. Elliott et al., 1990; Wilson, 2005), and that learners with high problem-solving efficacy tend to actively participate in problem-solving activities during learning, resulting in meaningful learning achievement (Greeno, 1991; Perkins et al., 1986). Regarding task value, Bong (2001) and Cole and colleagues (2008) found that learning gains are promoted when learners value the learning tasks. More specifically, Bong (2001) stated that utility value predicted learning achievement, while Cole and colleagues (2008) reported that attainment value and intrinsic value predicted university students' learning achievement. Teamwork competency is also reported as a significant predictor of achievement. For example, Hirschfeld et al. (2006) conducted a study using structural equation modelling, and reported that students' teamwork competency directly influenced team proficiency. Rundle-Thiele and Kuhn (2007) also reported that the perceived level of individual teamwork skill was a significant predictor of university student grades. Task authenticity is considered important, because learners are motivated to learn when learning activities are designed in realistic contexts (Herrington et al., 2004). This notion is supported in studies by Kang and her colleagues (2008) and Lee (2012), both of which reported positive effects of task authenticity on university student achievement.

Lastly, evidence for learner satisfaction as a predictor of achievement can be found in empirical studies by researchers such as Wang, Shannon and Ross (2013), and Chaparro-Peláez et al. (2013). Although most of the prior research claimed that the suggested predictors influenced learning achievement, this study used the level of *perceived* achievement instead of the direct measure of learning achievement. The major reason is that the participants were recruited from multiple universities that adopted different evaluation systems. Meanwhile, there existed some prior research that adopted perceived learning as a dependent variable (e.g. Chaparro-Peláez et al., 2013; Kang et al., 2008), while Kuhn and Rundle-Thiele (2009) claimed that the level of perceived achievement significantly explained the students' GPA. Although there exist differences between actual and perceived learning achievement, the researchers included the literature on actual achievement in order to establish the hypothesis of this study.

In sum, this study aimed to examine the structural relationships between factors that affect learner satisfaction and achievement in capstone design courses, specifically, problem-solving efficacy, task value, teamwork competency, and task authenticity. Figure 1 represents the model that was tested in this study, and the model was formulated in the research question as follows: What are the relationships between problem-solving efficacy, task value, teamwork, task authenticity, student satisfaction and perceived achievement, in the context of project-based learning in a capstone course for final year engineering undergraduates?

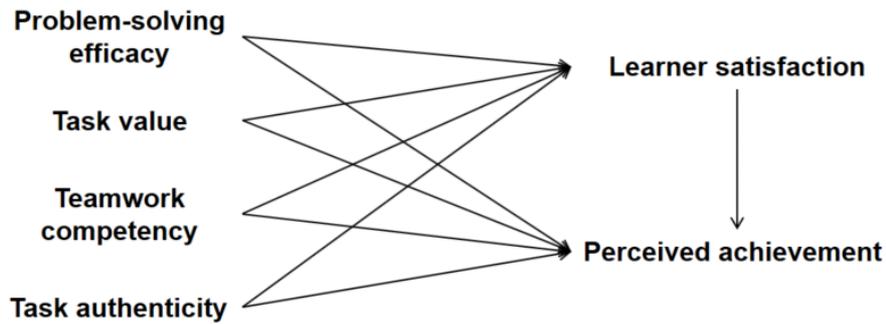


Figure 1: Hypothesised research model

Methods

Participants

The study participants were 363 engineering students enrolled in capstone design courses at four universities located in Seoul, South Korea in colleges of engineering that had been accredited by ABEEK; convenience sampling was used to select the courses. All of the participants were senior students, and 238 were male, while 125 were female. In terms of affiliation, there were 164 students from University A, 98 from University B, 69 from University C, and 32 from University D. Because the participants came from multiple universities, mean differences in each variable among institutions were analysed using ANOVA; for all of the research variables, such as problem-solving efficacy, task value, teamwork, task authenticity, satisfaction, and perceived learning achievement, there were no significant differences among institutions, as p values ranged from .09 to .88. That is, differences due to the participant affiliation to university were not a significant factor. In addition, differences in the research variables by gender were examined using t-tests; there were also no significant differences, as p values ranged from .06 to .75. Regarding previous experiences with PBL, all of the participants were expected to have been exposed to smaller scale project-based learning before entering this course, because the ABEEK requires all the accredited engineering programs to provide entry-level, project-based design courses prior to the capstone course.

The capstone design courses had been designed for senior students, and the general course design and criteria for performance assessment followed the guidelines suggested by ABEEK. Even though they were held at four different universities, the courses shared highly similar course structures based on project-based learning, although the details of the projects were different by university. In other words, the students participated in authentic or real-world projects, including defining or representing the problem, analysing needs, designing solutions, developing prototypes, evaluating and sharing results, and documenting processes and products. More specifically, required deliverables included team progress reports in regular-basis, individual design notes; final presentations on the project outcomes; and team final reports. The course instructors and teaching assistants

provided both cognitive and affective supports when necessary, and upon request as well. Invited lectures from the relevant field expert and regular meetings with the teaching staff were also provided. Sixty-four percent of the participants worked on team projects in groups of three to five, while twenty-four percent worked in groups of six to seven, and thirteen percent worked in groups of two. Regarding the origin of the tasks, sixty-one percent of the students worked on student-generated projects, while thirty-three percent worked on instructor-assigned tasks. The remaining six percent worked on industry-driven projects.

Instruments

Survey instruments that measured problem-solving efficacy, task value, teamwork competency, task authenticity, satisfaction, and perceived achievement were used to collect data. First, the instrument that measured *problem-solving efficacy* was adopted from the scales developed by Heppner and Peterson (1982), which measured domain-specific efficacy relevant to problem solving. Researchers have translated the 11 items, and two experts in the field of educational technology validated the Korean translation; sample items are, “When I make plans to solve a problem, I am almost certain that I can make them work” and “I trust my ability to solve new and difficult problems.” The Cronbach’s alpha for this variable was .88.

Second, *task value* was measured using the *Self- and Task-Perception Questionnaire* developed by Eccles and Wigfield (1995). Specifically, seven items related to task value were used that measured intrinsic, attainment, and utility value using three, two, and two items, respectively. Sample items were, for intrinsic value, “The amount of effort that will take to do well in this capstone design course is worthwhile to me” and “I like doing the capstone design project.”; for attainment value, “It is important for me to get good grades in this capstone design course” and “I feel that, to me, being good at solving problems which involve the project is important.”; and for utility value, “Learning in this capstone design project is useful for what I want to do after I graduate and begin work” and “Learning in the capstone design project is useful for my future career.” The Cronbach’s alphas for the three value dimensions were .88, .70, and .86, respectively. The Korean translation of the scale that was used was also validated by field experts.

Third, *teamwork competency* was measured using the instrument developed by Choi (2011), comprising 23 items. The sub-constructs were goal setting (eight items), coordination (four items), communication (six items), and leadership (five items). Sample items are “I achieve most of my goals”, “I respect my teammates’ opinions on the project” and “I was able to lead the team in such a way each individual could play his or her role effectively.” The Cronbach’s alphas for the four sub-constructs were .89, .81, .80, and .85, respectively.

Fourth, *task authenticity* was measured using eight items adopted from Roelofs and Terwel (1997) and Petraglia (1998); sample items are, “The capstone design project is similar to the real-world projects” and “The capstone design project is useful and valuable”; the Cronbach’s alpha was .90.

Fifth, *satisfaction* was measured using a modified version of a five-item instrument developed by Joo, Ha, Park and Kim (2007); specifically, the items measured the student contentment with their learning experience in their capstone design courses. Sample items are “Overall, I was satisfied with this capstone design course” and “I would like to recommend this capstone design course to my friends”; the scale’s Cronbach’s alpha was .87.

Lastly, *achievement* was measured as individual students’ perceived levels of achievement. Because the capstone design courses that were sampled for this study had team performance-based assessment criteria for a variety of different projects, students’ perceptions of their achievement were used in order to maintain consistency in scale. In addition, some researchers have reported that perceived achievement tends to be valid when learning focuses more on process rather than product, or on learners’ participatory experiences during learning (Batista & Cornachione, 2005; Chaparro-Pelaez et al., 2013; Pike, 1993). The instrument for perceived achievement was developed based on the guideline; from ABEEK’s student performance criteria for capstone design; the Cronbach’s alpha was .92.

All of these instruments used 5-point Likert scales. A pilot test on the instruments was conducted by the engineering students who had taken similar capstone design courses in the prior semester. The construct reliability and both the convergent and discriminant validity were then examined.

Data collection and analysis

Paper-based surveys were distributed at the end of the fall semester from November to December, and the collected data were analysed using structural equation modeling (SEM). First, exploratory and confirmatory factor analyses were conducted to confirm the validity and reliability of the measurements. Second, descriptive statistics and correlation analysis were calculated using *SPSS*. Multivariate normality was checked using *AMOS*. In terms of the SEM, the goodness of fit indices used for this study were the minimum sample discrepancy (CMIN), Tucker-Lewis index (TLI), comparative fit index (CFI), and root-mean-square error of approximation (RMSEA); direct and indirect effects were tested using bootstrapping at the significance level of .05. Item parcels were used for unidimensional factors, such as problem-solving efficacy, task authenticity, satisfaction, and achievement, in order to reduce the number of parameters to estimate, as well as to ensure the assumption of multivariate normality (Kline, 2010).

Results

Table 1 presents the means, standard deviations, skewness, kurtosis, and correlation coefficients for all the measured variables. Skewness ranged from .24 to -1.14, and kurtosis from .10 to 3.84, supporting the normality assumption (Kline, 2010). Regarding correlations among the measured variables, all of the coefficients were statistically significant.

Table 1: Descriptive statistics and correlation coefficients (N = 363)

Measured variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 PSE1	-															
2 PSE2	.82*	-														
3 IV	.58*	.49*	-													
4 AV	.61*	.46*	.58*	-												
5 UV	.42*	.38*	.44*	.56*	-											
6 GS	.56*	.53*	.51*	.59*	.39*	-										
7 Coord.	.44*	.39*	.37*	.47*	.32*	.58*	-									
8 Comm.	.54*	.46*	.45*	.59*	.42*	.64*	.53*	-								
9 Ldshp	.54*	.49*	.49*	.56*	.42*	.65*	.50*	.77*	-							
10 TA1	.54*	.48*	.53*	.59*	.59*	.52*	.45*	.56*	.54*	-						
11 TA2	.56*	.50*	.53*	.55*	.56*	.50*	.49*	.54*	.53*	.84*	-					
12 SAT1	.56*	.48*	.59*	.56*	.61*	.47*	.37*	.50*	.51*	.75*	.71*	-				
13 SAT2	.53*	.44*	.50*	.48*	.48*	.46*	.32*	.49*	.47*	.64*	.58*	.81*	-			
14 Ach. 1	.60*	.53*	.56*	.57*	.49*	.59*	.48*	.55*	.54*	.67*	.68*	.72*	.67*	-		
15 Ach. 2	.62*	.52*	.55*	.58*	.52*	.59*	.49*	.60*	.60*	.67*	.67*	.73*	.69*	.84*	-	
16 Ach. 3	.59*	.47*	.51*	.55*	.50*	.53*	.47*	.55*	.55*	.59*	.62*	.71*	.68*	.77*	.83*	-
Mean	3.8	3.5	3.8	4.2	3.9	3.9	3.8	4.0	4.0	3.9	3.8	3.8	3.9	3.9	3.9	4.0
Std dev	.53	.59	.79	.59	.86	.59	.66	.53	.58	.68	.67	.74	.74	.64	.62	.61
Skew.	-.32	.24	-.61	-1.1	-.60	-.37	-.34	-.63	-.58	-.67	-.61	.80	-.91	-.40	-.51	-.65
Kurtosis	.94	.10	.71	3.8	.08	.48	.91	2.9	1.9	.71	.99	1.01	1.6	.58	.84	1.3

Notes: * $p < .05$

PSE=Problem-solving efficacy; IV=Intrinsic value; AV=Attainment value;

UV= Utility value; GS = Goal setting; Coord. = Coordination; Comm. = Communication

Ldshp = Leadership; TA = Task authenticity; SAT = Learner satisfaction; Ach. = Achievement

Assessment of the measurement model

The result of maximum likelihood estimation indicated that the measurement model exhibited a good fit with the study data. Although the χ^2 showed significant results, which indicated lack of satisfactory model fit, there are limitations in its use due to its sensitivity to sample size (Hair, Black, Babin & Anderson, 2009). Therefore, the TLI, CFI, and RMSEA were used to test the model fit, and all reflected good fit, as presented in Table 2. In other words, the measurements of the latent variables included in the model were valid.

Regarding convergent validity, the standardised factor loadings ranged from .65 to .99, indicating the adequate validity of all the factors in the measurement model, in that all loadings were greater than .50. Discriminant validity was also examined following the criteria suggested by Anderson and Gerbing (1988). Since each of the correlation coefficients among latent variables $\pm 2 \times$ standard error was less than 1 in 95% confidence interval, the measurement demonstrated discriminant validity. Therefore, the measurement model appeared to fit the data well, and did not need to be changed.

Table 2: Fit statistics for the measurement model (N = 363)

	CMIN(χ^2)	<i>p</i>	<i>df</i>	TLI	CFI	RMSEA (90 % confidence interval)
Measurement model	210.54	.00	89	.97	.96	.06 (.05~.07)
Criteria (Browne & Cudeck, 1993)	-	-	-	> .90	> .90	< .08

Structural model and hypothesis testing

As a next step, the structural model was tested, and the proposed relationships among variables were analysed. The initial structural model provided a good fit to the data (TLI = .97; CFI = .98; RMSEA = .06). In order to test the first research hypothesis, the direct effects of problem-solving efficacy, task value, teamwork competency, and task authenticity on learner satisfaction were examined at the alpha level of .05 by reviewing the beta weights. The results showed that the direct effects from task value and task authenticity were statistically significant as follows: task value \rightarrow satisfaction: $\beta = .51$ ($t = 3.24$, $p < .05$); and task authenticity \rightarrow satisfaction: $\beta = .52$ ($t = 5.89$, $p < .05$). Problem-solving efficacy and teamwork competency did not have significant effects on satisfaction. Regarding the second research hypothesis, problem-solving efficacy, teamwork competency, task authenticity, and satisfaction had significant effects on perceived achievement: problem-solving efficacy \rightarrow achievement: $\beta = .14$ ($t = 2.60$, $p < .05$); teamwork competency \rightarrow achievement: $\beta = .33$ ($t = 4.43$, $p < .05$); task authenticity \rightarrow achievement: $\beta = .15$ ($t = 2.00$, $p < .05$); and satisfaction \rightarrow achievement: $\beta = .50$ ($t = 6.13$, $p < .05$). However, task value was not a significant factor for achievement.

The non-significant path coefficients were removed from the structural model to keep the model concise, and the modified model exhibited a good fit, as shown in Table 3. As a result, the modified structural model was confirmed as the final model, and that model's standardised path coefficients were re-examined, as illustrated in Figure 2.

Table 3: Fit statistics for the modified structural model (N = 363)

	CMIN(χ^2)	<i>df</i>	TLI	CFI	RMSEA (90% confidence interval)
Hypothesised model	210.544	89	.97	.98	.06 (.05~.07)
Modified model	214.536	92	.97	.97	.06 (.05~.07)
Criteria	-	-	> .90	> .90	< .08

Based on the modified model, learner satisfaction was assumed to mediate task value and perceived achievement, as well as task authenticity and perceived achievement. These indirect effects were also tested using bootstrapping (Preacher & Hayes, 2008). First,

satisfaction fully mediated task value and achievement ($\beta = .17, p < .05$). Second, satisfaction partially mediated task authenticity and achievement ($\beta = .25, p < .05$), given that there was also a direct effect of task authenticity on achievement ($\beta = .14, p < .05$). Table 4 decomposes the coefficients for direct and indirect effects.

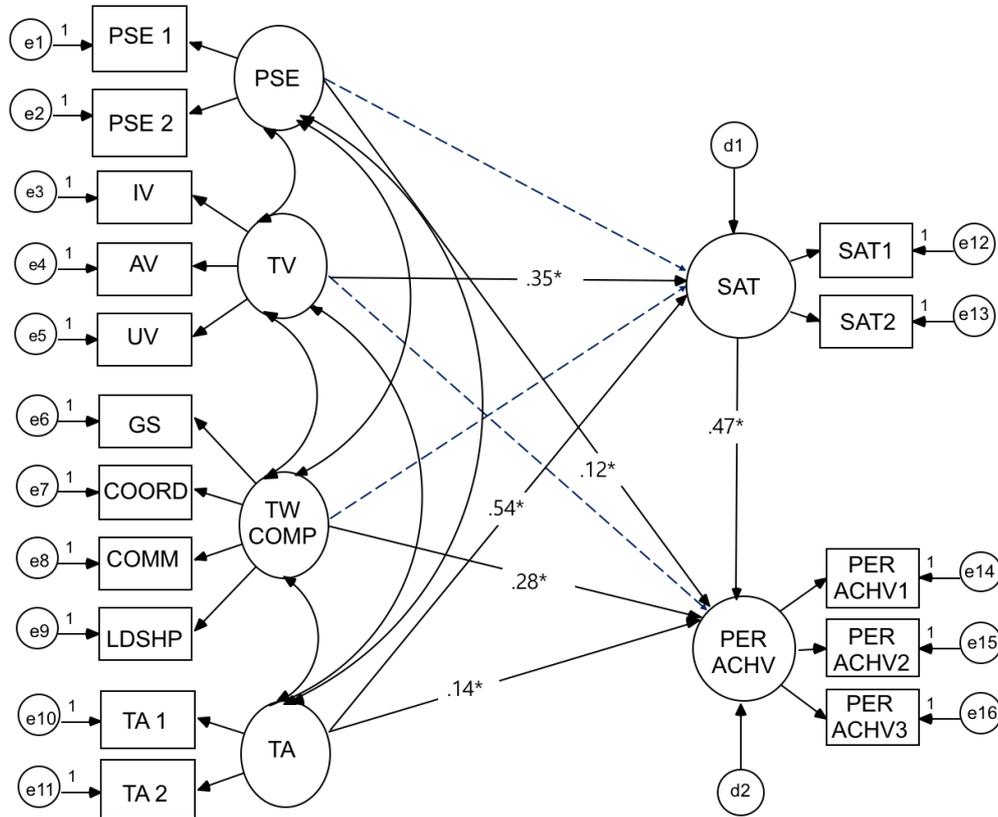


Figure 2: Modified model with standardised path coefficients

Notes: PSE = Problem solving efficacy; TV = Task value; IV = Intrinsic value; AV = Attainment value; UV = Utility value; TW COMP = Teamwork competency; GS = Goal setting; COORD = Coordination; COMM = Communication; LDSHP = Leadership; TA = Task authenticity; SAT = Satisfaction; PER ACHV = Perceived achievement.

Table 4: Effect decomposition for the modified model (N = 363)

Variables		Unstandardised coefficient (B)			Standardised coefficient (β)		
		Direct	Indirect	Total	Direct	Indirect	Total
Satisfaction	← Problem-solving efficacy	-	-	-	-	-	-
	← Task value	.44	-	.44	.36	-	.36
	← Teamwork competency	-	-	-	-	-	-
	← Task authenticity	.59	.59	-	.54	-	.54
Perceived achievement	← Problem-solving efficacy	.13	-	.13	.12	-	.12
	← Task value	-	.17	.17	-	.17	.17
	← Teamwork competency	.35	-	.35	.28	-	.28
	← Task authenticity	.13	.23	.35	.14	.25	.39
	← Satisfaction	.38	-	.38	.47	-	.47

Discussion

This study examined the structural relationships between factors that affect learner satisfaction and perceived learning achievement in capstone design courses for engineering students. Specifically, problem-solving efficacy, task value, teamwork competency, and task authenticity were included for analysis in the structural equation research model. The major findings of this study are as follows. First, variables that exerted significant effects on learner satisfaction were task value and task authenticity; this result does not support the implications from prior studies, such as Liaw (2008), in that problem-solving efficacy was not a significant predictor of satisfaction. This is partly because the context of this study was collaborative environments, in which team effort was required throughout the semester. Given that research settings for prior studies were mostly individual learning environments, this result implies that efficacy related to team, rather than individual, skills may be more critical for learner satisfaction.

Regarding the effects of task value and task authenticity on satisfaction, the results indicate that instructional strategies for developing authentic tasks, as well as promoting learners' positive awareness of the given project tasks, are important for increasing learner satisfaction in project-based capstone design courses. It was especially notable that the perceived level of task authenticity had the strongest beta weight on satisfaction in the final research model. In other words, authentic, learner-centred environments based on constructive strategies are appropriate for increasing learner satisfaction (Neo & Neo, 2009). Because capstone design is relatively new in college education in South Korea, strategies to promote learner satisfaction are highly important for diffusing the innovation.

Second, problem-solving efficacy, teamwork competency, task authenticity, and satisfaction exerted significant effects on learning outcomes, but task value did not; unsurprisingly, task value did not have a direct effect on perceived achievement, but an indirect one through satisfaction. Prior research on expectancy-value theory reported that perceived value was important in choosing or continuing specific tasks or behaviour (Eccles, 1984; Meece et al., 1990), and it indirectly predicted perceived achievement through the mediator engagement (Cole, 2008). In contrast, it is interesting that problem-solving efficacy predicted perceived achievement, but failed to predict satisfaction. According to Jonassen (2000), not only cognitive, but also motivational factors, such as attitudes toward and beliefs regarding problem solving, play important roles in solving complex, ill-structured problems. This result indicates that strategies for providing learners with successful problem-solving experiences are required. In this research context, it is notable that most of the students are likely to have problem-based design project experiences prior to this senior-level capstone course. Students may have had an opportunity to be aware of themselves in terms of learning which is centred around problem-solving. This self-awareness regarding the problem-solving efficacy might have played a critical role between the level of problem-solving efficacy, satisfaction, and achievement in a project-based capstone design course. Regarding teamwork, learners showed higher perceived achievement when they had higher levels of teamwork competency. That is, learners with goal-setting, coordination, communication, and leadership skills tended to perform better in project-based capstone design courses.

The practical implications based on the findings are: First, the effects of problem-solving efficacy on perceived achievement showed the importance of motivational factors in the capstone design courses. Therefore, supporting and fostering problem-solving efficacy with a long-term perspective is required. For example, activities that nurture positive mastery experiences, sharing success cases with peers, and providing process-oriented feedback are effective for developing problem-solving efficacy. More directly, problem-solving within the context of conducting a project could be used more extensively in courses prior the senior-level capstone design course. This elaborated curriculum tends to provide small-scale success experiences, which will affect the level of efficacy (Cassidy & Eachus, 2002). Second, the effects of task value on satisfaction and achievement imply the importance of providing situated tasks; specifically, instructional strategies that highlight task utility value, and providing environments in which learners can share that value would be meaningful. Third, the effect of teamwork competency on achievement suggests that formal and informal opportunities to develop teamwork competency are required in higher education, specifically for project-based courses. Fourth, the significant effects of task authenticity on satisfaction and perceived achievement indicate the importance of providing authentic tasks and authentic learning environments. Authenticity can be enhanced through cooperation with field industries, interaction with field experts, multidisciplinary team composition, and so forth. Lastly, learner satisfaction was revealed as a key factor in successful learning in capstone design courses; instructors and course designers need to consider learner satisfaction as a critical indicator in evaluating capstone design courses.

Based on the results of this study, further research is suggested as follows. First, one limitation of this study was the small sample size, and increased sample sizes from various regions are required to improve the generalisability of the findings. In addition, studies on different types of capstone design courses, for example, for a single semester versus a full year, for instructor-assigned versus student-generated project tasks, and for industry-involved versus non-industry involved projects, will provide more elaborated implications for instructional designers and instructors. Second, the learning outcome measures should be modified to include rubrics, peer reviews, instructor evaluations, and other objective sources, to overcome the limitations of self-reported data. Third, group-level variables based on teams could be added to the model, in order to investigate the relationships between personal and group-level variables. When the unit of analysis is teams, new insights for team project-based learning can be derived to better understand capstone design.

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