International Journal of Engineering Education Vol. 39, No. 6, pp. 1308–1317, 2023
Printed in Great Britain
0949-149X/91 $3.00+0.00

The Relationship Between Self-Regulated Learning Behavior and Attitudes in Project-Based Learning Classes: A Case Study*

YU-SHENG LIN[1] AND YU-HSUAN LIN[2]**
[1] Department of Mechanical Engineering, Southern Taiwan University of Science and Technology, Tainan, 710301, Taiwan.
E-mail: yushenglin@stust.edu.tw
[2] Department of Economics, The Catholic University of Korea, Gyeonggi-do, 14662, Republic of Korea.
E-mail: yuhsuan.lin@catholic.ac.kr

This study aims to explore the relationship between students' learning behavior, perceptions of project-based learning (PjBL), and learning outcomes in the context of engineering education. The study presents a case study of PjBL implementation at a private university in Taiwan, offering valuable insights from the instructor's perspective. A survey was conducted with 209 students in PjBL classes and 50 students in non-PjBL classes, focusing on six key learning indicators: learning attitude, participation attitude, academic integration, academic conscientiousness, application attitude, and satisfaction. The findings reveal that students' self-regulated learning attitude has a significant impact on their satisfaction and application attitude, mediated by their participation attitude, academic integration, and academic conscientiousness. The study provides empirical evidence supporting the effectiveness of PjBL in enhancing self-regulated learning, student engagement, and satisfaction levels. Moreover, it suggests that fostering a self-regulated learning attitude can motivate students to actively participate in the learning process, enhance their academic integration skills, and ultimately influence their satisfaction and application attitudes. This study underscores the potential of PjBL in improving students' employability and equipping them with the necessary skills to tackle challenges in the engineering profession. The insights gained from this research can inform educational practices and curriculum design to promote effective project-based learning experiences in engineering education.

Keywords: project-based learning; self-regulated learning behavior; mechanical engineering education; course implementations; Taiwan

1. Introduction

1.1 Project-based Learning in Engineering Education

Project-based learning (PjBL) has gained significant traction in engineering education, particularly in regions such as Northern Europe and China [1, 2]. In PjBL, students actively participate in specific projects that require extensive investigation, research, design, creation, and presentation of final products. These projects are typically rooted in real-world problems or scenarios. While PjBL and problem-based learning (PBL) have different underlying motivations and pedagogical philosophies [1], there is some overlap between both approaches in sharing a student-centered focus. Moreover, they both emphasize active engagement, critical thinking, and problem-solving skills. This study does not aim to delve into the differences between PjBL and PBL. Instead, our focus is on understanding the students' perspective and facilitating the implementation of PjBL in practice.

The benefits of PjBL are evident in the development of students' abilities in planning, communication, problem-solving, and decision-making [3]. PjBL places a strong emphasis on the practical application of theory, fostering creativity and innovation. It has proven to be effective in cultivating problem-solving and innovation skills among engineering students [4]. By applying the knowledge acquired from various courses, students enhance their problem-solving skills and improve their employability [5]. Previous studies, such as [6] and [7], highlighted that students can enhance a range of professional skills, including teamwork, proactivity, innovation, leadership, oral and written communication, and problem-solving, which go beyond traditional textbook learning. PjBL stands out from traditional learning environments by promoting interdisciplinary education and the development of interdisciplinary ideas and practices [8, 9]. Moreover, PjBL could have a beneficial impact on student learning effectiveness and engagement [10]. Active and experiential learning in PjBL maximizes the effectiveness of a hands-on approach, providing a more engaging and enriching teaching and learning experience compared to the traditional theoretical approach advocated by many engineer-

** Corresponding author.

* Accepted 30 June 2023.

ing programs [11]. These skills are crucial for students' employability and can be developed to an advanced level.

Apart from the challenges associated with implementing PjBL, such as managing resources and addressing technical issues, instructors also encounter student-related challenges, including low motivation and difficulties in guiding students' skills and knowledge [12]. PjBL requires learners to exhibit a significant level of autonomy and self-direction, which can be particularly challenging for students who thrive in more structured and guided learning environments. Without proper guidance, students may encounter difficulties in effectively identifying and solving problems.

1.2 Learning Behavior

Student learning behaviors are indicative of their attitudes toward learning. An empirical study conducted in Turkey revealed that learning attitudes play a crucial role in learners' goal setting, problem-solving abilities, beliefs about learning, intrinsic and extrinsic motivations, and overall academic performance [13]. Positive learning behaviors contribute to learners' knowledge and skill improvement.

Various studies have developed assessments to measure student engagement, cognition, motivation, behavior, attitudes, and self-efficacy in learning science [14, 15]. One well-known assessment tool is the Motivated Strategies for Learning Questionnaire (MSLQ), which evaluates students' motivation, use of cognitive strategies, and metacognitive abilities [16].

Self-regulated learning (SRL) encompasses effective behaviors in the learning process, such as task planning, performance assessment, and outcome reflection. Learning behaviors and strategies are essential skills for successful learning activities. For instance, note-taking requires cognitive effort as it involves summarizing and comprehending the context [17]. Previewing and reviewing are effective metacognitive learning strategies that demonstrate a learner's engagement and performance in the classroom [18, 19].

1.3 Learning Behavior in PjBL and PBL

The literature extensively discusses the role of learning behavior in PjBL and PBL, yet no consensus has been reached. On one hand, SRL is believed to contribute to successful PjBL and PBL outcomes. Studies suggest that SRL is a developmental process that enhances PBL, emphasizing the importance of students taking responsibility for their learning by setting goals, monitoring progress, reflecting, and sustaining motivation throughout the project [20, 21]. On the other hand, PjBL and PBL can also promote SRL. Studies in engineering education have explored project-based embedded systems and PBL programs to foster self-directed learning skills [22, 23]. A study found that PBL courses increase students' readiness for self-directed learning, although some students may show lower scores [24]. Additionally, PBL can both promote SRL as a process within PBL and as an outcome of PBL interventions. The relationship between PBL and SRL could be mutually influential [25].

This study aims to investigate students' learning behaviors in PjBL classes. PjBL was implemented in five third-year undergraduate courses in Taiwan, and a specific course's teaching methodology is presented in the following section. To gather data, a questionnaire was administered at the end of the semester to collect student feedback on various aspects, including learning behavior, participation attitude, application attitude, student satisfaction, academic integration, academic conscientiousness, and their PjBL experience. The collected feedback was then compared with that of two non-PjBL courses.

To gain a deeper understanding of the role of learning attitudes in PjBL, the study formulated the following five hypotheses:

(HO1) Self-Regulated Learning (SRL) attitudes positively impact students' attitudes towards PjBL applications.
(HO2) SRL attitudes enhance student satisfaction with PjBL.
(HO3) Learning behavior (LA), participation attitude (PA), academic integration (AI) and academic conscientiousness (AC) directly influence student satisfaction (SA) and application attitude (AT).
(HO4) LA indirectly affects SA and AT through its influence on PA, AI, and AC.
(HO5) PA, AI, and AC are correlated.

By analyzing the effects of SRL attitudes, participation attitude, academic integration, and academic conscientiousness, the study found that SRL learner autonomy influences student satisfaction and application attitudes through a complex process. The structure of the paper is as follows: Section 2 presents a case study of PjBL in mechanical engineering education in Taiwan. Section 3 outlines the design of the student survey and provides data details. Section 4 presents the data analyses. Section 5 discusses the results, and the final section concludes the paper.

2. A PjBL Case Study in Mechanism

This paper presents a case study conducted at a university in Taiwan, focusing on the implementation of PjBL in an undergraduate course on *Mechanisms*. The study aimed to address the learners' preference for practical application and active learning rather than passive lectures and industrial experience. PjBL was employed to facilitate a deeper understanding of the course content, as it was believed that learning by doing is more effective than learning by simply observing.

The course primarily covered the theories and methods of mechanism analysis, which involves the study of moving elements and the comprehension of machines composed of these elements. Associated application courses included mechanics, computer-aided design, computer-aided drawing, and machine design. Many students struggled to grasp the course material when focusing solely on mathematical formulas and calculations without considering their real-world implications.

The course was divided into two parts. The first part consisted of 13 weeks of theory lectures, software training, and exercises. The second part spanned five weeks and involved PjBL sessions. The PjBL learning process encompassed several steps: (1) conducting a literature review and customer survey, (2) defining specifications, (3) designing methods and coordination, (4) documenting the project, and (5) assessment. In the initial phase, students had to understand the needs of the target group by conducting interviews or surveys and staying informed about current technological advancements and limitations. Based on this understanding, they developed designs that fulfilled the requirements and addressed the identified gaps.

The primary objective of implementing PjBL in the course was to enable students to engage in the process of mechanism design and apply their knowledge and skills to practical applications. This approach aimed to enhance their coordination and communication abilities. The mechanism design process was initiated by customer requirements, which were then converted into engineering specifications by the mechanism design engineers. To fulfill these requirements, students employed mechanism analyses and other engineering skills such as computer-aided drawing and design. Evaluating the designs from multiple dimensions was an essential part of meeting the specified requirements.

Each project group comprised three or four students who collaborated to complete a project related to a common social problem that inspired them. For instance, one project involved designing mechanisms to assist parents with newborn feeding and burping. Prior to commencing the project, the instructor provided guidelines, reference materials, weekly progress checklists, and evaluation criteria. In the PjBL approach, the roles of instructors and students shifted to "facilitators" and "constructors" respectively [26]. The instructor regularly attended group meetings and offered advice. In accordance with a research team's suggestion [27], the instructor observed student discussions and provided feedback and relevant information to stimulate further discussions or new thinking when necessary. Peer effects also played a motivating role for students, and careful group arrangement and task division were recommended to minimize free riding [28]. To assess each team member's contributions, weekly attendance checks at group meetings and comprehensive peer evaluations were conducted.

At the culmination of the project activities, each group presented their ideas through a 10-minute presentation and a written report. The evaluation criteria encompassed five items: oral presentation skills (such as expressiveness and time management), engineering capability (including technical drawing and mechanism analysis), feasibility (evaluating functionality and practicality of the specifications), creativity (assessing the novelty of concept design), and communication skills (both oral presentation and written composition). To determine the best and most feasible idea, the instructor and two external referees evaluated all student presentations and reports based on the established criteria. Additionally, to encourage creativity, peer evaluation was employed to identify the most innovative ideas, irrespective of their feasibility.

3. Student Feedback

To explore student feedback toward learning behavior, participation attitude, application attitude, student satisfaction, academic integration, academic conscientiousness, and PjBL experience, this study conducted interviews with 209 students from five PjBL classes and 50 students from two non-PjBL classes in the Department of Mechanical Engineering. The interviews were conducted at the end of the 2021 and 2022 academic years. Data from 2021 were collected from in-person courses, while data from 2022 were collected from hybrid courses due to social distancing measures.

The questionnaire used in this study consisted of seven parts: self-regulated learning behavior (6 items, rated on a 5-point Likert scale), classroom participation attitude (12 items, rated on a 5-point Likert scale), application attitude (5 items, rated on a 5-point Likert scale), student satisfaction (4 items, rated on a 5-point Likert scale), academic integration (3 items, rated on a 5-point Likert scale), academic conscientiousness (3 items, rated on a 5-point Likert scale), and perception toward the PjBL approach (6 items). In line with a previous study, respondents were also asked to indicate their use of instructional strategies when facing learning difficulties, as strategy use has been found to be correlated with project performance [29]. Additionally, two open-ended questions were included to gather information about what the students liked and disliked about the course.

To ensure content validity, the learning behavior items were modified from those of previous related questionnaires [30–32]. Learning behavior captures students' attitudes toward learning, attention, and task completion. Questionnaires on academic integration, academic conscientiousness, student satisfaction, and strategy use were obtained from previous empirical studies [33, 34].

3.1 Data Description

This study utilized six items to allow students to self-evaluate their self-regulated learning behaviors. The results revealed that non-PjBL students reported lower levels of self-regulation, with average scores ranging from 3 (sometimes) to 4 (often) in PjBL courses, and between 2 (occasionally) and 3 (sometimes) in non-PjBL courses. Previewing learning materials before lectures was the lowest-ranked item, while engaging in classroom activities and taking notes during lectures were the highest-ranked items. The analysis of variance (ANOVA) indicated that the average scores for all items, except taking notes (Q3), were significantly higher in PjBL classes than in non-PjBL classes (Q1, p = 0.001; Q2, p = 0.0006; Q4, p = 0.0004; Q5, p = 0.0043; Q6, p = 0.0000). This suggests that most students in both classes felt more engaged in classroom activities than outside the class.

Regarding students' attitudes toward participation, twelve items (Q7–Q18) were used. PjBL students generally had positive attitudes, with average scores of over three on all items except for three inverse items (Q14–Q16). The highest-ranked items were Q13 ("*Actively discuss with teammates in group discussion*"), Q11 ("*Ask my classmates when I did not understand*"), and Q18 ("*When teammates felt difficulty, we cheer for each other*"). ANOVA analyses suggested that for items Q8–Q13, students in PjBL classes were more engaged in classroom activities than those in the non-PjBL classes. Regarding student-to-student and student-to-teacher interactions (Q8, p = 0.002; Q9, p = 0.000; Q10, p = 0.000; Q11, p = 0.025; Q12, p = 0.003), the PjBL students were more active in asking the instructor and classmates, but there was no significant difference in answering the instructor's questions (Q7). In terms of group activities, the PjBL students were significantly more engaged in group discussions (Q13: p = 0.002), but there was no significant difference in efficient communication or consensus on the inverse items (Q14–Q16).

Regarding their application attitude, PjBL students showed a positive attitude toward applying what they had learned (average scores on items: Q19, 3.41; Q20, 3.36; Q21, 3.50; Q22, 3.37; Q23, 3.31). In particular, they believed that they could connect the lecture content with the real world (Q21). The PjBL students had significantly more positive attitudes than the non-PjBL students for all five items (Q19, p = 0.006; Q20, p = 0.000; Q21, p = 0.000; Q22, p = 0.000; Q23, p = 0.039).

Three items (Q28–Q31) were related to the students' academic integration abilities. Both PjBL and non-PjBL students had positive attitudes, but PjBL students had more positive attitudes than did non-PjBL students (Q28: p = 0.003; Q29: p = 0.000; Q30: p = 0.000). In contrast, another three inverse indicators (Q31–Q33) were used to assess students' academic conscientiousness. The majority of the PjBL and non-PjBL students also believed that they were conscientious on all three items. However, PjBL students were found to be significantly more diligent than non-PjBL students in terms of being interested in class and working hard (Q33, p = 0.007).

Regarding student satisfaction, most students were satisfied with four items (Q24–Q27), particularly the one regarding smooth communication between lecturers and students (Q27). The PjBL students were significantly more satisfied than the non-PjBL students for all four items (Q24, p = 0.000; Q25, p = 0.000; Q26, p = 0.000; Q27, p = 0.004).

In terms of instructional strategies used to resolve misunderstandings, almost half of both the PjBL and non-PjBL students reported asking their peers on social media apps such as *Line*, *WhatsApp*, *Facebook*, and *Instagram*. Other commonly used methods include checking online resources such as *YouTube* videos and *Google* materials, reviewing lecture notes or class videos, and asking peers about videoconferencing apps such as *Zoom*, *Webex*, *Microsoft Teams*, and *Google Hangouts*. There were no significant differences in the strategies used by both the PjBL and non-PjBL classes. The study found that students in both groups were equally likely to reach out to their peers when facing difficulties, highlighting the important role of peer support in facilitating learning and problem-solving.

Six items (Q38–Q43) were used to assess the PjBL students' experiences with this learning approach. Three responses were provided for each item: yes, no, and uncertain. Students in this study reported being unfamiliar with PjBL, with less than 30% of them having previously participated in PjBL. However, most of them were positive and felt refreshed by this approach. More than 90% of the students felt that they knew the obligations of the project and worked with their teammates to complete it. They also believed that the project had enhanced their knowledge. The lowest scores were for two items: Q41, in which only 83.7% of the students were satisfied with their project, and Q43, in which only 81.8% of the students thought the project enhanced their practical skills.

Students also reported their feelings about PjBL through two open-ended questions: *what did you like* and *what did you dislike in this course*? We divided the students' answers to the two open-ended questions into five categories: instructor, equipment, field trip, team, and application. Most respondents claimed that the PjBL design helped them build connections through practical work. However, some felt a lack of freedom due to the assigned topic, some had no experience and did not find a connection with the topic, and some struggled to find teammates and coordinate with others.

Overall, the PjBL approach motivated the students to engage in group activities. Despite the lecture content being less than that of traditional lectures because of the activities, this approach focuses on a specific topic and builds a bridge to connect with other related professional courses. As most of them felt positive and were capable of applying their technical skills to the project, the PjBL approach worked to motivate passive learners.

4. Data Analyses

To examine the relationship between learning behavior and student performance, we used the average scores to represent student self-regulated learning behavior (LA: Q1–Q6), participation attitude (PA: Q7–Q18), application attitude (AT: Q19–Q25), student satisfaction (SA: Q24–Q27), academic integration (AI: Q28–Q30), and academic conscientiousness (AC: Q31–Q33). While six items (Q14–Q16 and Q31–Q33) were inverse indicators, they were reversed to match the same attitude direction as the other items.

4.1 Group Differences

Significant class differences were observed in various indicators, including learning behavior (LA, $p = 0.001$), participation attitude (PA, $p = 0.001$), student satisfaction (SA, $p = 0.000$), academic integration (AI, $p = 0.011$), and academic conscientiousness (AC, $p = 0.003$). These findings indicate that students may have different perceptions based on their enrolled course units. Furthermore, notable differences were also identified between the two survey years, particularly in participation attitude (PA, $p = 0.034$) and academic conscientiousness (AC, $p = 0.020$). The stricter social distancing measures implemented in 2022 resulted in all classes and activities being conducted remotely, which contributed to lower scores in participation attitude and academic conscientiousness among the students.

Supportive equipment can enhance the efficiency of resource-finding in PjBL. For example, Chen found that an adequate system can facilitate learner contemplation and cooperative learning as learners interact with their peers during cooperative PBL [35]. Moreover, a study suggested that novel artificial intelligence-aided techniques and resources can improve the teaching-learning process in higher education, especially in connection with engineering education [36]. However, Chaparro-Peláez and Iglesias-Pradas argued that negative experiences with a simulation tool could adversely affect perceived learning in PBL [37]. In our study, students provided open-ended feedback on the equipment used. Most students had positive comments about advanced mechanical tools but negative comments about the software. Those who made positive comments had higher satisfaction (SA, $p = 0.001$) and academic conscientiousness (AC, $p = 0.000$) compared to those who did not.

A previous study suggested that the use of innovative social networks could enhance students' interest in learning and increase peer interaction in PBL [38]. For example, low-achieving students could be encouraged to engage in discussions on the concise messaging platform, *Plurk*. However, in our study, we did not find a significant difference in learning indicators among the six most frequently used instructional strategies.

Six items (Q38–Q43) asked about the students' experiences and self-assessed achievements in PjBL. The options for these items were agree, disagree, and uncertain. We found that students who were uncertain about their ability to find resources for the project had significantly lower LA and PA scores ($p = 0.005$ and $p = 0.001$, respectively) than those with the ability mentioned in item Q39. This suggests that student confidence affects their learning attitudes and participation. However, confidence did not affect application attitudes or satisfaction.

For items Q40 and Q41, students were asked about their perceptions of their projects. Students who thought that their team did not coordinate well had lower PA scores ($p = 0.047$) than those who coordinated well. For item Q41, students who were dissatisfied with their project work had lower LA scores ($p = 0.05$) than those who were satisfied with their work. However, those who were uncertain about the project quality had lower PA scores ($p = 0.019$) than those who were satisfied with their work.

Table 1. Correlations between learning indicators

	(1)	(2)	(3)	(4)	(5)	(6)
(1) Learning behavior (LA)	1					
(2) Participation attitude (PA)	0.68***	1				
(3) Application attitude (AT)	0.65***	0.69***	1			
(4) Satisfaction (SA)	0.61***	0.71***	0.71***	1		
(5) Academic integration (AI)	0.59***	0.62***	0.77***	0.78***	1	
(6) Academic conscientiousness (AC)	0.16*	0.31***	0.03	0.19**	0.13	1

Source: this study (N = 209). Note: *, **, ***: $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

Items Q42 and Q43 asked students if they thought the project could enhance their knowledge and practical skills. Those who did not think the project could enhance their knowledge had lower scores on LA ($p = 0.026$), PA ($p = 0.012$), and AT ($p = 0.002$) than those who believed their knowledge was enhanced in item Q42. Those who did not think or were uncertain about whether the project could enhance their practical skills had lower scores on PA ($p = 0.034$ and $p = 0.01$, respectively), AT ($p = 0.039$ and $p = 0.000$, respectively), and SA ($p = 0.013$ and $p = 0.002$, respectively) in item Q43. In the following section, we explore the correlations between the learning indicators.

4.2 Correlations between Learning Indicators

Table 1 presents the correlations between the six learning indicators. Our findings indicate that students' LA was significantly correlated with all indicators except AC, although the correlation coefficients were not particularly high. In contrast, other indicators such as student satisfaction, participation attitude, application attitude, and academic integration showed stronger correlations. Notably, application attitude was highly correlated with academic integration, which is reasonable, given that connecting knowledge with related courses enables students to apply their knowledge in practice. However, academic conscientiousness did not show a high correlation with the other indicators. Thus, further investigation is necessary to understand the role of learning behaviors in PjBL.

4.3 Linear Regression

Hypotheses HO1 and HO2 suggest that student satisfaction (SA) and application attitude (AT) in PjBL are affected by learning behavior (LA), participation attitude (PA), academic integration (AI), and academic conscientiousness (AC). The regression estimations in Table 2 reveal the predictors of student satisfaction with and application attitudes toward PjBL. A collinearity test confirmed that there was no collinearity in the estimations. Our results show that SA was positively associated with PA and AI but inversely associated with AC. AT was positively associated with both PA and AI. However, LA was not a significant predictor of SA or AT. The significant constant terms suggest that factors other than the independent variables may be included in the model.

4.4 Structural Equation Modeling (SEM)

To test hypotheses HO3, HO4 and HO5, structural equation modeling (SEM) was used to investigate the structural relationships between the measured variables. Unlike the regression mentioned earlier, SEM provides an overall view of all indicators by estimating multiple and interrelated dependencies.

The results indicates that the goodness of fit for the proposed model was good (χ^2/df = 1.38, CFI = 1.00, TLI = 0.993, RMSEA = 0.005). After establishing the model fit, the SEM results were investigated. The Cronbach's alpha coefficient was 0.8452, suggesting that the six indicators (observed variables) had relatively high internal consistency. Table 3 shows the results of the SEM model analysis, and Fig. 1 shows the standardized SEM model.

The model indicates that the average SA score was directly influenced by AI and PA (positively), whereas AT was directly influenced by LA, PA, AI (positively), and AC (inversely). The average PA, AI, and AC scores were directly affected by LA (positive). LA had a significant indirect and positive influence on SA and AT (positively) through PA, AI, and AC. Thus, AC was positively influenced by LA and significantly inversely influenced by AT. It

Table 2. Regression estimates

Variable Item	SA	AT
LA	0.08	0.08
PA	0.40***	0.40***
AI	0.51***	0.51***
AC	0.01	0.01
Constant	0.76**	0.76***
Observations	209	209
R-squared	0.696	0.696
Adj R-squared	0.690	0.690

Source: this study (N = 209). Note: *, **, ***: $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

Table 3. Structural equation modeling analysis

Effect	Pathway			Estimate	S.E.
Direct	SA	←	LA	0.08	0.06
			PA	0.40***	0.08
			AI	0.51***	0.05
			AC	0.01	0.36
	AT	←	LA	0.16**	0.06
			PA	0.41***	0.07
			AI	0.46***	0.05
			AC	–0.13***	0.03
	PA	←	LA	0.56***	0.04
	AI	←	LA	0.66***	0.06
	AC	←	LA	0.20*	0.08
Indirect	SA	←	LA	0.57***	0.06
	AT	←	LA	0.51***	0.06
Total	SA	←	LA	0.64***	0.06
		←	PA	0.56***	0.04
		←	AI	0.51***	0.05
		←	AC	0.01	0.03
	AT	←	LA	0.67***	0.05
		←	PA	0.41***	0.07
		←	AI	0.46***	0.05
		←	AC	–0.13***	0.03
	PA	←	LA	0.56***	0.04
	AI	←	LA	0.66***	0.06
	AC	←	LA	0.20*	0.08

Source: this study (N = 209). Note: *, **, ***: $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

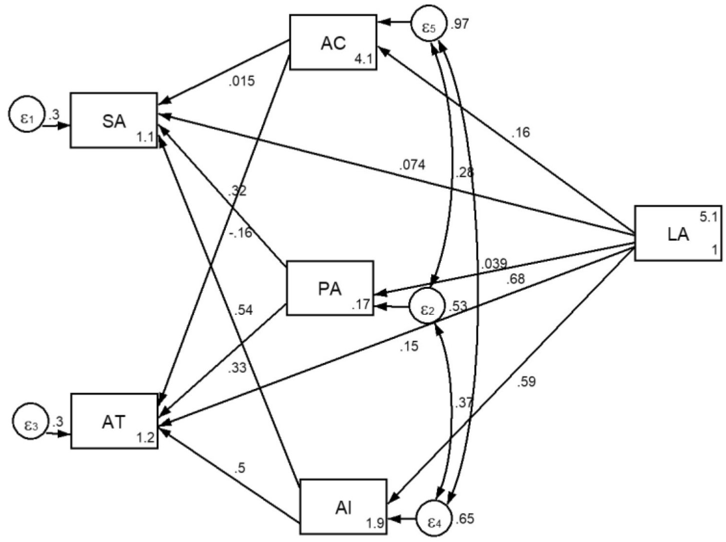

Fig. 1. Structural equation modeling model (standardized estimates).

is worth noting that PA was positively correlated with AC and AI, respectively, while AC and AI were not significantly correlated with each other.

5. Discussions

Although numerous studies have examined PjBL and its impact on students' attitudes, this study offers insights into the relationship between self-regulated learning behavior and attitudes in PjBL courses using two methods. Firstly, we present a case study showcasing the implementation of PjBL in an undergraduate course on *Mechanisms* at a university in Taiwan. This case study provides a step-by-step process that outlines guidelines for effectively implementing the PjBL teaching approach. Secondly, we employ a quantitative method to compare students' learning behavior and attitudes in PjBL and non-PjBL courses.

The case study yields two valuable classroom implementations for instructors. Firstly, PjBL proves to enhance teamwork and communication skills. To foster effective communication, implementing a peer assessment strategy in the classroom can facilitate students' learning motivation and discourage free riding. Secondly, as previous studies [8, 9] have suggested and our study reaffirms, PjBL promotes interdisciplinary education and enhances students' professional skills. Students are required to integrate knowledge from various subjects and apply it to industry-relevant projects. Guiding students to understand customer demands and encouraging them to develop customer-oriented specifications has proven to be beneficial in achieving this goal.

Our findings based on students' feedback indicate that scores for most survey items were significantly higher in PjBL classes compared to non-PjBL classes. This finding aligns with previous studies [11] and [39] which also demonstrated the effectiveness of PjBL in various aspects of teaching and learning. Students in PjBL classes exhibited higher levels of SRL attitudes, greater engagement in class activities, and increased satisfaction with their learning experiences. This result is consistent with previous research indicating that PjBL fosters students' creative thinking skills and self-regulated learning [22]. However, when students encountered difficulties in their learning, there was no significant difference in the use of instructional strategies between PjBL and non-PjBL students. Both groups primarily sought assistance and resolved questions by consulting their peers through social media applications.

Second, our study finds strong correlations among SRL learning attitude, participation attitude, academic integration, academic conscientiousness, student satisfaction, and application attitudes. Regression analyses reveals that participation attitude and academic integration significantly influenced learning outcomes in terms of satisfaction and application attitudes. However, learning attitude and academic conscientiousness did not show significant associations with either outcome. These findings differ from previous studies that suggested SRL as a developmental process that enhances problem-based learning [20]. Therefore, our results do not support hypotheses HO1 and HO2, indicating that learning attitudes may have distinct roles in the PjBL learning process.

Lastly, the SEM analysis conducted in this study reveals that the relationships between learning factors and learning outcomes are more complex than initially hypothesized in HO1 and HO2. Partial support was found for hypothesis HO3, indicating that participation attitude and academic integration had direct effects on satisfaction and application attitudes. Furthermore, SRL learning attitude indirectly influenced these outcomes through its impact on participation attitude and academic integration. However, SRL learning attitude only had indirect effects on satisfaction through participation attitude and academic integration. These findings suggest that students' application attitude is influenced by multiple factors, while their satisfaction is primarily influenced by their participation and academic integration. Partial support was also observed for hypothesis HO4, indicating that learning attitude indirectly affected application attitudes through participation attitude, academic integration, and academic conscientiousness. Additionally, hypothesis HO5 received partial support, indicating that participation attitude was correlated with academic integration and academic conscientiousness, while the latter two factors were not correlated with each other. These results underscore the intricate nature of the relationship between SRL and learning outcomes, emphasizing the need for further exploration in this area.

6. Conclusions

This study explores the relationship between self-regulated learning behavior and attitudes in PjBL courses. Firstly, the study provides guidelines for implementing PjBL effectively, emphasizing its benefits in enhancing students' learning experiences and promoting learner autonomy and engagement. Instructor feedback, peer influence, and group arrangement are identified as important factors in maximizing the advantages of PjBL.

Secondly, a quantitative analysis is conducted to compare learning behavior and attitudes between PjBL and non-PjBL courses. The findings reveal class differences, the impact of supportive equipment in PjBL, the influence of instructional strategies, and students' perceptions of their PjBL experiences. Significant variations are observed in learning behavior, participation attitude, student satisfaction, academic integration, and academic conscientiousness across different class groups and survey years. Students in PjBL classes exhibit higher levels of self-regulated learning attitudes, increased engagement in class activities, and greater satisfaction with their learning experiences. The stricter social distancing measures in 2022 resulted in lower scores in participation attitudes and academic conscientiousness.

Thirdly, strong correlations are found among learning indicators and outcomes. Regression analyses demonstrate that participation attitude and academic integration significantly influence learning outcomes in terms of satisfaction and application attitudes. However, learning attitude and academic conscientiousness do not show significant associations with these outcomes. Thus, the study's results challenge the initial hypotheses and suggest distinct roles for learning attitudes in the PjBL process.

Finally, the SEM analysis reveals a more complex relationship between self-regulated learning and learning outcomes than initially hypothesized. Participation attitude and academic integration directly impact satisfaction and application attitudes, while learning attitude indirectly influences these outcomes through its effects on participation attitude and academic integration. Satisfaction is primarily influenced by participation and academic integration, while multiple factors influence application attitude. These findings underscore the complexity of the relationship between self-regulated learning and learning outcomes, calling for further investigation in this area.

In conclusion, this study highlights the positive impact of PjBL in engineering education, emphasizing its ability to motivate students and apply technical skills to real-world projects. The importance of nurturing self-regulated learning behavior, participation attitude, academic integration, and academic conscientiousness to enhance student satisfaction and application attitude is emphasized. Further research and exploration in this field can contribute to the ongoing improvement of engineering education practices.

Acknowledgements –This study was supported by the Ministry of Education (MOE) in Taiwan for Teaching Project Practice Research Program (PEE1123023). The authors declare that there is no conflict of interest.

References

1. M. Bauters, J. Holvikivi and P. Vesikivi, An overview of the situation of project-based learning in engineering education, *SEFI 48th Annual Conference Engaging Engineering Education Proceedings*, pp. 56–64, 2020.
2. S. Lin, Z. Tan and W. Guo, A bibliometric analysis of project-based learning research in and outside mainland China, *International Journal of Engineering Education*, **39**(2), pp. 376–396, 2023.
3. R. Amini, B. Setiawan, Y. Fitria and Y. Ningsih, The difference of students learning outcomes using the project-based learning and problem-based learning model in terms of self-efficacy, *Journal of Physics: Conference Series*, 2019.
4. A. Shekar, Project-based learning in engineering design education: sharing best practices, *2014 ASEE Annual Conference & Exposition*, pp. 24.1016. 1–24.1016. 18, 2014.
5. V. Upadhye, S. Madhe and A. Joshi, Project based learning as an active learning strategy in engineering education, *Journal of Engineering Education Transformations*, **36**(Special Issue 1), 2022.
6. M. Foss, Y. Liu, and S. Yarahmadian, Project-based learning in a virtual setting: a case study on materials and manufacturing process and applied statistics, *International Journal of Engineering Education*, **38**(5), pp. 1377–1388, 2022.
7. M. Vargas, T. Nuñez, M. Alfaro, G. Fuertes, S. Gutierrez, R. Ternero, J. Sabattin, I. Banguera, C. Duran and M. A. Peralta, A project based learning approach for teaching artificial intelligence to undergraduate students, *International Journal of Engineering Education*, **36**(6), pp. 1773–1782, 2020.
8. S. J. Martínez Fernández, C. Gómez Seoane, and V. Lenarduzzi, Applying project-based learning to teach software analytics and best practices in data science, *International Journal of Engineering Education*, **39**(2), pp. 476–487, 2023.
9. S.-W. Kim, An Interdisciplinary Capstone Course on Creative Product Development with Cross-College Collaboration, *International Journal of Engineering Education*, **36**(3), pp. 919–928, 2020.
10. M. Umar and I. Ko, E-learning: direct effect of student learning effectiveness and engagement through project-based learning, team cohesion, and flipped learning during the COVID-19 pandemic, *Sustainability*, **14**(3), p. 1724, 2022.
11. N. H. Jabarullah and H. Iqbal Hussain, The effectiveness of problem-based learning in technical and vocational education in Malaysia, *Education + Training*, **61**(5), pp. 552–567, 2019.
12. M. Aksela and O. Haatainen, Project-based learning (PBL) in practise: Active teachers' views of its' advantages and challenges, *Integrated Education for the Real World*, 2019.
13. H. Ş. Şen, The attitudes of university students towards learning, *Procedia – Social and Behavioral Sciences*, **83**, pp. 947–953, 2013.
14. M. Lovelace and P. Brickman, Best practices for measuring students' attitudes toward learning science, *CBE–Life Sciences Education*, **12**(4), pp. 606–617, 2013.
15. E. Panadero, A review of self-regulated learning: six models and four directions for research, *Frontiers in Psychology*, **8**, 2017.
16. P. R. Pintrich and E. V. De Groot, Motivated strategies for learning questionnaire, *Journal of Educational Psychology*, 1991.
17. T. Makany, J. Kemp and I. E. Dror, Optimising the use of note-taking as an external cognitive aid for increasing learning, *British Journal of Educational Technology*, **40**(4), pp. 619–635, 2009.
18. E. Cook, E. Kennedy and S. Y. McGuire, Effect of teaching metacognitive learning strategies on performance in general chemistry courses, *Journal of Chemical Education*, **90**(8), pp. 961–967, 2013.
19. B. Flanagan, R. Majumdar, K. Takii, P. Ocheja, M. Chen and H. Ogata, Identifying student engagement and performance from reading behaviors in open eBook assessment, *Proceedings of the 28th International Conference on Computers in Education*, pp. 235–244, 2020.
20. S. M. Loyens, J. Magda and R. M. Rikers, Self-directed learning in problem-based learning and its relationships with self-regulated learning, *Educational Psychology Review*, **20**(4), pp. 411–427, 2008.
21. M. C. English and A. Kitsantas, Supporting student self-regulated learning in problem-and project-based learning, *Interdisciplinary Journal of Problem-Based Learning*, **7**(2), p. 6, 2013.

22. J. Larson, S. S. Jordan, M. Lande and S. Weiner, Supporting self-directed learning in a project-based embedded systems design course, *IEEE Transactions on Education*, **63**(2), pp. 88–97, 2020.
23. R. M. Marra, D. J. Hacker and C. Plumb, Metacognition and the development of self-directed learning in a problem-based engineering curriculum, *Journal of Engineering Education*, **111**(1), pp. 137–161, 2022.
24. T. A. Litzinger, J. C. Wise and S. H. Lee, Self-directed learning readiness among engineering undergraduate students, *Journal of Engineering Education*, **94**(2), pp. 215–221, 2005.
25. H. Leary, A. Walker, M. Lefler and Y.-C. Kuo, Self-directed learning in problem-based learning, in *The Wiley Handbook of Problem-Based Learning*, pp. 181–198, 2019.
26. H.-C. Li and A. J. Stylianides, An examination of the roles of the teacher and students during a problem-based learning intervention: lessons learned from a study in a Taiwanese primary mathematics classroom, *Interactive Learning Environments*, **26**(1), pp. 106–117, 2018.
27. H.-T. Hou, K.-E. Chang and Y.-T. Sung, An analysis of peer assessment online discussions within a course that uses project-based learning, *Interactive Learning Environments*, **15**(3), pp. 237–251, 2007.
28. J. Chen, J. Zhu and T. Zheng, From initiators to free-riders: exploring the spectrum of female engineering students' functional roles in project-based learning using phenomenography, *International Journal of Engineering Education*, **38**(4), pp. 917–933, 2022.
29. K. Zhao and Y. Zheng, Chinese business English students' epistemological beliefs, self-regulated strategies, and collaboration in project-based learning, *The Asia-Pacific Education Researcher*, **23**(2), pp. 273–286, 2014.
30. B. J. Zimmerman and M. Martinez-Pons, Construct validation of a strategy model of student self-regulated learning, *Journal of Educational Psychology*, **80**(3), p. 284, 1988.
31. L. Barnard, W. Y. Lan, Y. M. To, V. O. Paton and S.-L. Lai, Measuring self-regulation in online and blended learning environments, *The Internet and Higher Education*, **12**(1), pp. 1–6, 2009.
32. M. D. Dixson, Measuring student engagement in the online course: The Online Student Engagement scale (OSE), *Online Learning*, **19**(4), p. n4, 2015.
33. W. B. Davidson, H. P. Beck and M. Milligan, The college persistence questionnaire: Development and validation of an instrument that predicts student attrition, *Journal of College Student Development*, **50**(4), pp. 373–390, 2009.
34. Y. D. Murdoch and Y.-H. Lin, Factors mediating the link between engagement and satisfaction among online English-mediated Instruction learners during COVID-19, *The Electronic Journal of e-Learning*, **21**(3), pp. 158–174, 2023.
35. C.-M. Chen, An intelligent mobile location-aware book recommendation system that enhances problem-based learning in libraries, *Interactive Learning Environments*, **21**(5), pp. 469–495, 2013.
36. J. L. Martin Nunez and A. Diaz Lantada, Artificial intelligence aided engineering education: State of the art, potentials and challenges, *International Journal of Engineering Education*, **36**(6), pp. 1740–1751, 2020.
37. J. Chaparro-Peláez, S. Iglesias-Pradas, F. J. Pascual-Miguel and Á. Hernández-García, Factors affecting perceived learning of engineering students in problem based learning supported by business simulation, *Interactive Learning Environments*, **21**(3), pp. 244–262, 2013.
38. S.-H. Huang, Y.-M. Huang, T.-T. Wu, H.-R. Chen and S.-M. Chang, Problem-based learning effectiveness on micro-blog and blog for students: a case study, *Interactive Learning Environments*, **24**(6), pp. 1334–1354, 2016.
39. A. Yadav, D. Subedi, M. A. Lundeberg and C. F. Bunting, Problem-based learning: Influence on students' learning in an electrical engineering course, *Journal of Engineering Education*, **100**(2), pp. 253–280, 2011.

Yu-Sheng Lin is an assistant professor in the Department of Mechanical Engineering at the Southern Taiwan University of Science and Technology. His research focuses on the application of AIoT technology in the healthcare industry and medical devices. Dr. Lin has a strong expertise in markerless motion analysis and mechatronics integration, particularly in the development of rehabilitation devices. His work involves leveraging state-of-the-art artificial intelligence and machine vision technologies to transform healthcare devices. Understanding the challenges that students encounter in keeping up with rapid technological advancements, Dr. Lin advocates for interdisciplinary collaboration and hands-on experiential learning. He actively leads pedagogical research initiatives aimed at fostering student interest and enhancing their learning experiences. Driven by a passion for innovation and education, he strives to empower students to become future leaders in the field by equipping them with practical skills and a comprehensive understanding of cutting-edge technologies. ORCID identifier: 0000-0001-8653-8685

Yu-Hsuan Lin is an associate professor in the Department of Economics at The Catholic University of Korea. His research focuses on innovative teaching approaches and higher education reform. One of his primary areas of interest is the development of a hybrid teaching approach that combines flipped learning, project-based learning, and classroom experiments. ORCID identifier: 0000-0002-4014-2586