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Fostering Interdisciplinary Learning in a Smart Living Technology Course through a PBL Approach*

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A project-based learning approach is proposed and tested in this study to explore its feasibility and the effectiveness of such a pedagogical framework to guide instructors and learners in an interdisciplinary learning context. Objective data from summative evaluations were collected to understand students' performance and attitude in their project-based learning experiences, as well as to explore whether the interdisciplinary project-based learning approach improves students' abilities to perform project work. The results of this study showed that students did improve their ability to work on group projects through the engagement and experience of this interdisciplinary PBL. Also, students performed well on their final projects, for the instructors were satisfied with their group project performances. Students also expressed positive attitudes toward the interdisciplinary PBL approach as an effective instructional strategy. Based on the findings of this study, discussion and recommendations are provided on future issues in engineering education, both for practical application as well as research.

Keywords: interdisciplinary learning; engineering education; project-based learning; smart living technology

1. Introduction

The industrial sector in Taiwan is facing severe pressure to provide low-cost manufacturing and high-value production. Entrepreneurs are moving to shift the economy away from the traditional reliance on low-end manufacturing and heavy investment spending and seeking to build a strong base in the technology-intensive and high-return information industry [1]. In addition, to share resources to push innovation forward with a shorter time to market, more and more companies are consolidating and synergizing. The resulting jobs, which are much more collaborative and interdisciplinary in scope, require not only solid technical competencies but manifold abilities spanning disciplines from engineering to business management. In support of this trend, government policies have accelerated development over the past decade in a series of national projects, including e-Taiwan (2002–2007), m-Taiwan (2005–2009), u-Taiwan (2007–2011), and noticeably i-Taiwan (2009–2012), to continuously develop the industry of smart living technologies. These large-scale projects have involved the joint endeavors of manifold departments in education, research, technology, and industry to systematically respond to the urgent and immense demand for human resources, who are expected to have more holistic knowledge and higher-order thinking skills to work together with professionals and talents from different disciplines for rapid innovation and increased productivity [2–4].

Since the creation and growth of industry depends on human capital to a large extent, a comprehensive education policy emphasizing multidisciplinary learning is crucial to positive change in the industry sector. In response to industry practices that require high levels of interdisciplinary collaboration and interaction, efforts have been made in industrial training and school curricula to develop engineering professionals and talents who seek meaningful connections among disciplines that are intertwined in the real world. Earlier and repeated exposure to interdisciplinary perspectives and experiences in school education are regarded as important if these future employees [5] are to develop multi-professional skills and advanced epistemological beliefs to understand the relationships among different disciplines. Business and industry have partnered with academia on innovation, technology transfer, and the education of the workforce. However, traditional studies and training in engineering education are discipline-specific in nature, with a definite goal of preparing novice learners for specialization. The current curricula have been criticized for being fragmented and too limited in scope to meet students' educational and practical goals [6–8], and more attention is being paid to the idea of interdisciplinary learning in educational research and practices [8, 9].

Despite the clear importance of interdisciplinary

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learning, substantial barriers to its implementation remain [10]. Leveraging the teaching and learning from multiple disciplines can be difficult due to the foundational influences of disciplinary pedagogies and educational goals [11]. Pedagogies incorporating collaborative and inquiry-based learning are popularly adopted in interdisciplinary teaching methods [12] to accommodate the needs of multidisciplinary students learning altogether. However, for novice learners, who possess few meta-cognitive skills to make sense of the interactions among the different disciplines, the students cannot be left to piece together disciplinary responses. Instead, an advanced pedagogical framework is greatly needed to guide the instructors in integrating and facilitating student learning. Occasioned by the aforementioned issues, a project-based learning approach is proposed and tested in this study to explore the feasibility and effectiveness of such a pedagogical framework to guide instructors and learners in an interdisciplinary learning context. Summative evaluation was conducted to understand student performance and attitudes in their project-based learning experiences, as well as to explore whether the interdisciplinary project-based learning approach improves students' abilities to work on projects.

2. Teaching-learning methodology: A project-based learning approach for interdisciplinary teaching and learning

Project-based learning (PBL), a structured set of learning activities introduced in the early twentieth century to motivate student self-learning [13], has been incorporated to a great degree in many programs in higher education sectors. From the first, effective application in engineering education [14] to pre-service teacher development programs across disciplines [15], project-based learning has been proved to be effective because it fosters the integration of academic and operational approaches to higher education and instills a high level of motivation for active learning. Project-based learning features learning activities in which learners work collaboratively over an extended period of time to solve an authentic and challenging problem and produce an end product to conclude their learning [16]. It can also be viewed as an activity in which students foster understanding of a topic or issue through involvement in solving a real-life problem. Additionally, project-based learning echoes the needs of the 21st century for competency in an extensive and up-to-date store of knowledge, as well as problem-solving and teamwork skills. It involves the assumptions of cognitive and social processes of learning and values interactions in problem-centered environments [17].

Previous studies in project-based learning have supported the idea that collaborative and project-based activities facilitate interdisciplinary connections and higher levels of university engagement with industry to meet modern job requirements [18–20]. Unlike problem-based learning, which focuses on learners' reasoning abilities, project-based learning has attracted particular interest in engineering education because of its potential to increase student engagement and improve skill development [21]. Nevertheless, due to extreme variation within its short history, project-based learning encompasses a diversity of approaches, and no unique model or consistent paradigm has been adopted. The fundamentals comprise the driving questions and the tasks that lead to the production of a final product [22], which anchor and motivate students to construct an internalized framework of all the related perspectives, concepts, ideas, and methods of inquiry [23]. These characteristics of project-based learning, which enhance opportunities for interdisciplinary learning, help students to perceive the connections among seemingly unrelated domains and facilitate a personalized process of organizing knowledge [15]. As [24] noted, the features of project-based learning contribute greatly to interdisciplinary learning. An interdisciplinary project can serve as a catalyst to facilitate students' cognitive, affective, and skill-oriented learning by providing team tasks that intertwine challenges from various disciplines [25, 26]. The composition of interdisciplinary student teams will positively influence students' perception of learning outcomes across the intellectual, practical, social, and personal dimensions in PBL engineering courses [27]. Also, cognitive (i.e., guidance, clarification, and suggestion) and affective (i.e., comment, confirmation, and encouragement) support must be provided by interdisciplinary instructors to facilitate the PBL learning process [28].

In learners' accounts, project-based learning is widely reported to be well-received, as measured by mandatory student satisfaction surveys and informal feedback [29, 30]. However, the significant investments of time and resources by the instructors in both the development and the implementation stages of project-based learning often discourage instructors from adopting it [31]. Moreover, instructional support in developing resources and materials and technological support in managing massive amounts of content and interactions in class are strong requirements [32]. For a context with interdisciplinary instructors and students, a guiding framework, as suggested by previous studies [33], is essential to ensuring the effectiveness of teaching and learning. Also, there are different problem identified and solutions suggested by [33] to the difficulties instructors may encounter in adopting PBL in each phases. In consideration of the developmental nature of project-based learning, this current study adopted a PBL approach as the framework for detailed and committed team planning and increased resources to guide interdisciplinary instruction and learning.

3. Method

3.1 Participants

Forty-two learners and twenty-two instructors of various disciplines participated in this study. Regarding the students, thirty-five of them (83.3%) were at graduate level, and seven (16.7%) were at undergraduate level. Most of the student participants were from disciplines in science and engineering (83.3%), and 16.7% had backgrounds in the humanities and social sciences. Students formed 7 interdisciplinary groups of 5–6 members to work on the project-based learning activities for the semester. Collaborative teaching was provided by instructors from various disciplines, including engineering, natural science, medicine, the social sciences, the arts, and the humanities.

3.2 Context of the study

This study was conducted in a formal course entitled "Seminar of Smart Living Technologies" at the senior level at National Taiwan University. The theme of the course involved concepts and knowledge from different disciplines related to the development and application of smart living technology. For the 18-week course, one topic was assigned weekly and collaboratively taught in forms of paired team-teaching by two experts in engineering/science and the humanities/social sciences. The

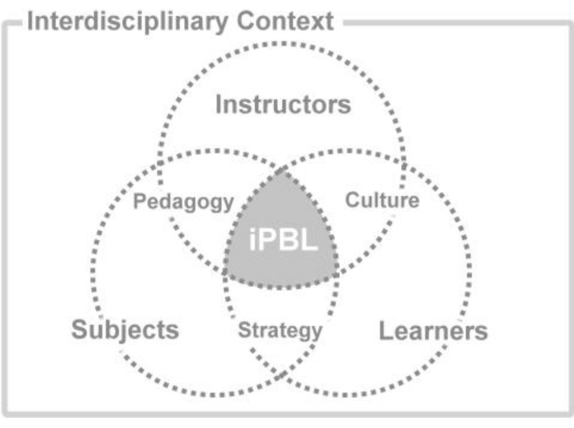

Fig. 1. The interdisciplinary context of this study.

interdisciplinary compositions of the subjects, instructors, and learners of the study made the overall context extremely complex. As shown in Figure 1, the instructors' teaching styles and methods may have been influenced by their primary institutions, and students with different backgrounds may have varied in terms of their comprehension and interpretation of the instructions because the subject matter involved interactions among manifold practical and theoretical issues across multiple disciplines.

In order to facilitate student learning and coordinate communications within the complicated network of interdisciplinary teachers, a course website was established to support the storage, presentation, and exchange of content materials for both lectures and project work. With the implementation of project-based learning, additional features were integrated into the course website to provide groups of students with space for their project activities, including synchronous chat and asynchronous discussion. The project-based learning approach implemented in this study was developed by [34] and revised in [32] for implementation in international distance courses for interdisciplinary participants, and it proved to be effective for project teamwork.

As shown in Figure 2, a three-stage framework was adopted to describe learners' tasks and activities during the project-based learning. The first stage of preparation focused on acquainting students with the thematic knowledge and main learning objectives of the course. In the beginning, smart living technologies were introduced and five predefined critical issues were disclosed, and students were required to form groups with members from both engineering/science and the humanities/social sciences to work on one of the issues as their project. This initiated the second stage of implementation. The five issues of application included attentive, sustainable, medical, infrastructure, and entertainment technologies that traversed the disciplines and skills of engineering, science, the humanities, and the social sciences (i.e., psychology and sociology), reflecting the interdisciplinary nature of smart living technologies. Extensive instructions regarding discipline-specific applications of smart living technologies were given in the second stage to acquaint students with manifold perspectives and methods. This stage ended with presentations by the students on their initial ideas for the projects, design plan, and projected schedules. For the final stage of completion, which focused on the evaluation and modification of the learners' projects, students made continuous modifications to the project artifacts in response to feedback from evaluations and their reflections on their progress in this course.

Fig. 2. The PBL model developed by this study.

3.3 Instruments

To evaluate students' abilities to complete project work and their learning performance, and to collect students' attitudes toward and feedback on the interdisciplinary engineering course, 3 instruments were developed by the researchers. The first, an assessment of the ability to work on group projects, was designed to collect students' perceptions of their group work abilities and to understand whether the interdisciplinary project-based learning approach improved students' abilities to plan and execute projects. This assessment was composed of six items scored on a 6-point Likert-type scale, followed by open-ended questions to understand students' background knowledge and project work or PBL experience. The second instrument was a group project performance evaluation form, which included seven items scored on a 6-point Likert-type scale to determine how well the students achieved the goals of their project work and open-ended questions to collect suggestions or comments on improving the project work and performance. The third instrument was the attitude survey on the interdisciplinary PBL approach, intended to collect students' attitudes toward this PBL group-learning experience. This survey questionnaire also had six items scored on the same Likert-type scale along with open-ended questions to collect students' reflections on their interdisciplinary PBL experience and other comments and suggestions regarding this approach. The items of assessments are presented in detail in Table 1.

4. Main results

4.1 Students' perceived abilities to work on group projects

To understand how the interdisciplinary PBL approach would affect students' abilities to work on projects, at the beginning and end of the semester, students were asked to self-evaluate their own related abilities. As shown in Table 2, at the beginning of the course, the students expressed that they were more proficient in collecting information (3.56), setting a learning goal (3.54), organizing and summarizing information (3.51), and developing a learning plan (3.56) than managing the learning progress (3.21) and self-evaluating the learning outcome (3.21). At the end of the semester, all six types of abilities were significantly improved ($t_{(38)}$ = 4.025 ~ 7.550, $p < 0.001$). The ability to organize and summarize information (4.51) improved the most, followed by collecting information (4.23), setting a learning goal (4.21), developing a learning plan (4.18), self-evaluating the learning outcomes (4.15), and managing the learning progress (4.08).

It was obvious that after a semester working with the interdisciplinary PBL approach, students perceived improvements in their abilities to work on group projects. The scores on all items improved, and the average score also increased from 3.41 to 4.23 ($t_{(38)} = 7.175$, $p < 0.001$), with statistically significant differences. As seen in the feedback from open-ended questions, students indicated that they had learned to see project teamwork as

Table 1. Research instruments adopted in this study

Instrument	Measurement	Administration
Assessment of ability to work on project work	Self-evaluation of project work abilities (6 items) Open-ended questions (reflections on previous project work or PBL experience, comments and suggestions)	Beginning of the course (pre-test) End of the course (post-test)
Group project performance evaluation form	Group project performance (7 items) Open-ended questions (Suggestions, comments to improve project work and performance)	Final group project presentation
Attitude survey of the Interdisciplinary PBL approach	Attitude toward the interdisciplinary PBL approach (6 items) Open-ended questions (reflections on interdisciplinary PBL experience, comments and suggestions)	End of the course

Table 2. Students perceived abilities to work on group projects: pre-test vs. post-test

	Pre-test		Post-test		
Item	**Mean**	**SD**	**Mean**	**SD**	**t**
1. Collecting information and reference resources	3.56	0.91	4.23	0.84	4.238***
2. Organizing and summarizing information	3.51	0.82	4.51	0.72	7.550***
3. Setting a learning goal	3.54	1.17	4.21	0.73	4.025***
4. Developing a learning plan	3.46	1.14	4.18	0.85	4.172***
5. Managing the learning progress	3.21	1.08	4.08	0.77	6.537***
6. Self-evaluating the learning outcome	3.21	0.92	4.15	0.78	6.096***
Average	3.41		4.23		7.175***

Table 3. Group project performance with the interdisciplinary PBL approach

Item	Mean	SD
The group successfully conveys the project concepts and ideas.	4.33	0.62
The concepts and ideas of the group project are complete.	3.80	0.72
The concepts and ideas of the group project are feasible and fit the course theme of Smart Living Technology.	4.38	0.67
The concepts and design of the group project are specific and practical.	4.13	0.61
The ideas and design of the group have great potential for actual implementation.	4.03	0.73
The group project is innovative and creative.	3.75	0.81
I like the ideas and design in this project.	4.08	0.76

more focused on collaborative work and understood the importance of project management. Therefore, they felt that they had developed better abilities to work on group projects after engagement in this interdisciplinary PBL work and believed it would help them in future learning and group work.

4.2 Group project performance evaluation

The overall evaluation of groups' project performance is presented in Table 3. Although students did not demonstrate high confidence in their abilities to work on group projects at the beginning, group project performance was generally good after a semester of interdisciplinary PBL work. Based on instructors' evaluations, the concepts and ideas proposed by each group were considered to be clearly conveyed, and more importantly, as feasible for the theme of smart living technology. With reference to the feedback from the open-ended questions, the results did reflect the authentic nature of the project-based learning activities. Also, students maintained that the exposure to interdisciplinary perspectives from the instructors from different institutions, including the industrial, education, and government sectors, helped them to cross-reference and integrate multidisciplinary perspectives. On the other hand, students thought that the interdisciplinary topics of the subject made it challenging for them to demonstrate creativity, since fundamental but discipline-specific knowledge could require considerable time and resources to learn. Figure 3 showed the real artifacts in different forms student groups developed that are challenging but they actually transformed the wide ideas into real products and prototypes.

4.3 Students' attitudes toward and reflections on the interdisciplinary PBL approach

Table 4 also sheds light on how students perceived their learning experience with the interdisciplinary PBL approach. On the attitude survey, the students expressed positive attitudes in all aspects. Specifically, they were interested in this interdisci-

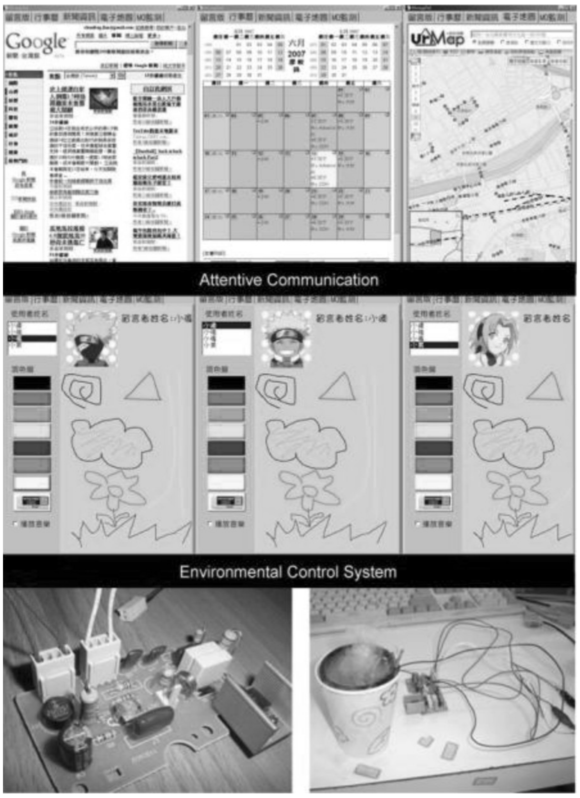

Fig. 3. Project artifacts of attentive communication and environmental control system. Top: Groupware for restaurant searching;

Table 4. Students' attitude toward the interdisciplinary PBL approach

Item	Mean	SD
I am interested in this interdisciplinary and interactive course.	4.38	0.73
I am motivated to active learning and participate in this course.	4.21	0.72
I have difficulty learning subject matter from other disciplines.	2.88	1.25
I enjoy learning the knowledge and skills presented in this course.	4.31	0.81
I enjoy interacting with peers from different disciplines.	4.26	0.94
I feel confident that my learning in this course will be successful.	4.29	0.67

plinary and interactive course (M = 4.38), motivated to actively learn and participate in this course (M = 4.21), enjoyed learning the knowledge and skills presented in this course (M = 4.31), enjoyed interacting with peers from different disciplines (M = 4.26), and felt confident that their learning in this course would be successful (M = 4.29). It is noteworthy that students did not have too much difficulty in learning subject matter from other disciplines (M = 2.88).

Furthermore, from the comments and feedback on the open-ended questions, for the whole semester, the activity that made the greatest impression on the students was the interdisciplinary PBL group work with collaborative learning. Students thought that their experiences with the interdisciplinary PBL approach had multiple advantages. In terms of communication, even though group members had different academic backgrounds, they were willing to express their opinions and communicate well under the PBL context. In terms of knowledge exchange, students expressed that they benefitted from the interdisciplinary brainstorming, which stimulated their minds, and they could understand the thinking patterns and research approaches of each member. In terms of project execution, the interdisciplinary team allowed members to bring their professions, including knowledge and skills, into full play and increased the degree of project practicality. Moreover, students gained an understanding of the values of the other disciplines and learned to respect one another's professions.

> "Collaborating with interdisciplinary group members can help me to understand other domains' research approaches and experience sharing." (s1)
>
> "I think the students that come from different domains not only have dissimilar perspectives toward the same issue but also have different approaches when conducting affairs. Even the report presentation style shows the differences with different backgrounds. However, the collaboration between humanities and technology students indeed can increase the project practicality, and we are able to know what ideas are feasible more quickly." (s2)
>
> "Under the collaboration among team members, everyone can bring their specialties into full play." (s3)

5. Discussion

The main purposes of this study were to examine how the project-based learning approach could be implemented in an interdisciplinary learning context and to explore its pedagogical effects and the feasibility of this approach for interdisciplinary engineering education. Results of this study showed that the interdisciplinary PBL approach could significantly help students to improve and develop the essential abilities for working on group projects. This finding is consistent with research by [35], who found that project process skills would be developed in an interdisciplinary problem-based learning environment in engineering education. In addition, due to the focus on a project artifact that anchored student learning to a final product, students' project concepts and outcomes were feasible and practical. Student motivation and focus were easier to maintain with a clear goal of a project artifact to be achieved.

In this study, the students believed on the first day that they would perform better on the abilities of collecting information, organizing information, setting learning goals, and developing the learning plan than on managing the learning progress and self-evaluation of the learning outcome. However, the differences among those abilities were not obvious after their involvement in the semester-long course and engagement in the interdisciplinary PBL work. Using pre-scheduled progress reports set by the instructors, students learned to review their project work for both the processes and the outcomes, which may have helped them develop the abilities and skills to better manage both their group project work and their individual learning strategies.

In general, students' group project performance was improved through this interdisciplinary PBL course. Under the project-based learning framework, students were aware of the necessary tasks and processes to be achieved and therefore managed to plan and execute the project effectively. The instructors could also follow the framework to monitor and facilitate students' learning and further provide necessary resources and assistance. As [36] pointed out, the interdisciplinary interactive project was a suitable method for demonstrating the practical needs of the professional engineering field. With regard to the group project performance in this study, the project outcomes were generally evaluated as feasible for the course theme, practical to be implemented, and successful in conveying the design concepts to the audience. The instructors, as evaluators, were satisfied with the ideas students presented, even though the innovation and completeness did not meet initial expectations. The combination of engineering and non-engineering students in interdisciplinary teams was intended to inspire students to view issues from various perspectives and to encourage the emergence of creative concepts through sharing and exchanging ideas between the humanities and technology professions. However, the relatively low numbers of non-engineering students in each group in this study might have resulted in a lack of more comprehensive understanding or considerations of humanities and social science perspectives during work on the group projects.

> "I would have to admit that my 'interdisciplinary' knowledge was really advanced through the lectures given by many professionals. As an engineering student, I was not familiar with those approaches and instruments in humanities and social science in the beginning. But during our interview with the elder users, I had this chance to see and realize how users' psychological features and the reality in their life should be taken into consideration, and could be inquired by the questionnaire." (s4)

Overall, the students expressed positive attitudes toward the interdisciplinary PBL approach. The comments and evaluation results indicated that the students were enthusiastic about participating in the course and valued learning interdisciplinary knowledge, interacting with team members from different disciplines, and developing confidence in learning. The results corresponded to past studies [37, 38] reporting that interdisciplinary learning could provide students with favorable and positive learning experiences, and that the students would express higher interest in the class, be simulated to think and learn, have effective communication and collaboration on the topics, learn a great deal, and acquire the ability to integrate disparate areas of knowledge. The findings support the success of using the instructional pedagogy of project-based learning as the guiding framework with a focus on the arrangement of themes and contents to be included in this newly developed interdisciplinary course.

6. Conclusion

From the experiences learned in this study, it is suggested that instructors should not merely introduce the PBL approach to the course; instead, they need to design learning issues and activities while providing useful supplementary materials as guidance to facilitate the project work. If the interdisciplinary knowledge contains multidimensional issues, such as the Smart Living Technology in this study, collaborative team-teaching by instructors across disciplines can effectively provide multiple perspectives to help students see the whole picture as they approach learning issues and project work.

Furthermore, this study adopted the pedagogical framework of project-based learning to contend with the rather complex context of multidisciplinary instructors and learners and interdisciplinary subject matter. Students affirmed the success of the interdisciplinary PBL approach according to the strategic guideline of applying disciplinary knowledge they had learned in the course, that also coined solutions to solve difficulties of project-based learning for greater success. More importantly, it is strongly supported that project-based learning facilitates students' integration of multidisciplinary perspectives into a focused artifact. On the other hand, the challenges encountered by the students in this study, such as insufficient communication and struggles to achieve innovative thinking, could be affected by the primary limitation of the enrollment structure of this course. While this study was conducted in a formal course for the sake of authenticity, control of the context was constrained at the same time. More operative design for educational experiments to equalize the compositions of the student groups is suggested for future studies. Also, more sophisticated learning activities should be developed to help enhance student communication and improve their comprehension of the new interdisciplinary learning context. Though the interdisciplinary PBL approach was demonstrated to be successful in this current study, and could serve as the basis for practical interdisciplinary learning applications, inferences from the findings of this case study should be drawn with caution and with attention to the context. It is recommended that further investigations also focus on the features of group members, the compositions of groups, and the interaction patterns of different groups.

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