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APPLYING ONLINE PEER ASSESSMENT WITH TOTAL QUALITY MANAGEMENT TO ELEVATE PROJECT-BASED LEARNING PERFORMANCE

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Abstract. *Undergraduate science, technology, engineering, and mathematics (STEM) curriculum emphasize project-based learning (PBL) with peer assessment/on-line peer assessment (PA/OPA). Many studies have stressed that students did not improve over two rounds in PBL with OPA studies and PBL with PA have to adopt team mutual cooperation to reap effective learning. This study proposed an innovative approach that incorporate OPA with TQM as a macro-level instructional tool to guide students in teacher's directing of collaborative project development as well as seeking continuous improvement to elevate Project-Based Learning Performance in a STEM course. The effects of OPA with TQM were examined through an experiment with PBL performances hypotheses. A total of 63 junior students in an university of Taiwan voluntarily participated in this study and a quasi-experimental approach with a two-group design was adopted. The results revealed that the team members using the OPA with TQM approach tended to have higher design skill performance, better cohesive teamwork and creative problem solving attitude. Thus, the proposed approach facilitated team members to collaborate for seeking continuous improvement. However, no significant difference was reported on the influence of enhancing students' design concept. Implication and suggestions for educators to promote the PBL with OPA and TQM were also provided in the study.*

Key words: *collaborative learning, online peer assessment, project-based learning, STEM course, Total Quality Management.*

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Introduction

In the education of undergraduate science, technology, engineering, and mathematics (STEM) in Taiwan, projects are an essential parts of the curriculum for training students in project-based learning as well as collaborative/cooperative learning. This is particularly true to engineering related programs because engineering education plays an important role in developing students' product design proficiency in response to demand of the industrial ear (Tseng, Chang, Lou & Chen, 2013).

The requisite skills of an engineer include coping with technical complexities, evolving solutions, working successfully in the future (Pospisil, 1996; Brown & Eisenhardt, 1995; Drucker, 1998; Sherma, 1999) by communicating effectively and performing well in interdisciplinary teams (Hirst & Mann, 2004; Sawhney & Prandelli, 2000; Sen & Engelhoff, 2000), and generating and commercializing innovative ideas which satisfy customer needs (Tomkovich & Miller, 2000; Debruyne et al., 2002; Thamhain, 2003; Hirst & Mann, 2004). Therefore, educators and institutes have been devoted to develop integrated education programs and learning strategies for STEM to achieve the aforementioned goals.

Project-Based Learning (PBL) enables the simulation of the real world phenomena, prepare students for future industrial practice. PBL is a learning method which highlights "learning by doing". Through the learning activities, learners take the initiative to identify problems, define questions, and find solutions (Liang, 2012). Learners can be equipped with knowledge and skills, as well as apply them to complete the project (Blumenfeld et al., 1991; Barrows, 1996; Thomas et al., 1999). However, some studies indicated that it is critical for PBL to adopt mutual team cooperation to bring up effective learning (Krajcik et al., 1994). Project participants must interact with people inside and outside of the project to gain adequate information, plan for strategies and actions, and promote their learning efficiently through learning from each team and competing with other teams (Poell

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& Van der Krogt, 2003). However, teamwork problems such as insufficient communication, uneven distribution of tasks, and the free-rider problems are also significant issues in student projects that jeopardized teamwork quality (Hoegl & Gemuenden, 2001).

The meanings of collaborative learning and cooperative learning are different. Brufee (1999) advocated that collaborative learning and cooperative learning have same goal to assist students while learning together in the journey of important knowledge and skills acquisition. The most vital factor of these two learning approaches is the facilitation of constructive communication among team members to achieve the learning objectives that a single person could not afford. According to Merriam-Webster's New International Dictionary, cooperation is defined as people work together through labor division and coordination. For example, if a group of authors wants to write a book, cooperation means that each member in the group who has his/her own accountability (e.g., one chapter) writes his/her accountable chapter by himself/herself rather than completing the whole book. Meanwhile, collaboration emphasizes common contribution instead of working together on the division of work. Therefore, if a group of authors wants to write a book collaboratively, they would write each chapter altogether.

Cooperative learning is an educational method that students of mixed levels of ability are arranged into groups and will be rewarded according to the aggregative success of the group rather than that of each individual member. Collaborative learning is also an educational treatment that more than two students work together to learn something. It is based on a general premise that groups of students can learn better from each other through sharing and social interaction than they would if they learned on their own. The collaborative learning concept is based on the idea that diversity of knowledge and experience positively impacts the learning outcomes.

Springer, Stanne and Donovan (1999) poised that "*collaborative learning is characterized by relatively unstructured processes through which participants negotiate goals, define problems, develop procedures, and produce socially constructed knowledge in small groups* (p. 24)". Moreover, according to the literatures of ERIC, the subjects of collaborative learning are usually undergraduate and graduate students, because collaborative learning aims to flip the traditional classrooms up especially in higher education settings where professors have supreme authority in that social structure. This traditional social structure might diminish students' freedom of thoughts and obstruct their possibility of creativity. The adoption of collaborative learning could provide students with autonomy, encourage them to speak, change their passive learning attitude into active ones, and enhance students' social skills, and cultivate the maturity of wisdom. Thus, the work reported in this paper focused on the collaborative learning approach. However, teachers applying the collaborative learning techniques in PBL, whether in the traditional or online forms, all encountered many issues. Challenges in collaborative learning such as insufficient communication, uneven distribution of tasks, dominance of a single member in a group (Williams & Karau, 1991), free-rider predicament (Strong & Anderson, 1990), and the sucker effect (Steiner, 1972) are all significant challenges in student projects, impacting the effective of teamwork as well as individual learning performance. The design of teamwork training and team management for capstone PBL must be structured to prevent the aforementioned problematic issues from arising.

Johnson and Johnson (1987) stressed that successful cooperative learning consists of five elements: (1) positive interdependent relationship among team members; (2) face-to-face interaction; (3) individual accountability; (4) collaborative skills training in advance; (5) monitoring and reflecting of group process. Hoegl and Gemuenden (2001) developed a comprehensive concept of collaboration in teams, termed Teamwork Quality (TWQ), which is conceptualized as having six dimensions: communication, coordination, balanced member contributions, mutual support, effort, and cohesion. Many researchers have attempted to respond to the aforementioned issues in the collaborative learning domain and Peer Assessment (PA) is a popular exemplary solution.

Peer assessment refers to any arrangement in which learners consider the amount, level, value, worth, quality or success of the learning outcomes of their peers (Topping, 1998). With the rapid development of information technology, Online Peer Assessment (OPA) enabled students to operate reflective thinking and clarify their misconceptions by providing a comfortable learning environment that is free from temporal and spatial constraints, and that allows participants to work and be graded anonymously (McConnell, 1999). Zhao (2000) pointed out that although anonymity had made it possible for students to dare to speak and enhanced the usefulness of feedback, yet, anonymity is like double-edged sword that students would not work as hard as they would in their homework without anonymity. Many approaches were designed for the establishment of personal accountability for each team member and relations of positive interdependence among team members by resource and/or reward interdependence (Kao, Lin & Sun, 2008; Johnson & Johnson, 1992, 2009; Lin, Sun &

Kao, 2002; Kao, 2013; Chen, Hong, & Chen, 2014). Nevertheless, some students found frustrations in PA owing to lack of clear instruction plan, evaluation guideline, and good teamwork (Orsmond & Merry, 1996; Clifford, 1999). Moreover, since persistence for pursuing improvement is vital to the success of PBL with OPA (Lin et al., 2001; Tsai et al., 2002; Tseng & Tsai 2007). Lin et al. (2001) found that many students did not improve over two rounds in an OPA study. Both Tsai et al. (2002) and Tseng & Tsai (2007) showed a similar finding--most students improved their work over three-round, which was an optimal situation. Still, how to inspire students' teamwork incentive, how to create their positive independence to fully participate in PBL with OPA, and how to encourage them to develop a continuous improvement processes are issues and threats for the performance of PBL. Capstone PBL for STEM education are supposed to help students to acquire knowledge and skills in how to function effectively in teams and to cultivate students' spirits of continuous seeking improvement before entering the workforce.

Total Quality Management (TQM) stresses improving product quality to meet customer needs by creating organization excellence at every level, through collaboration among team members, full participation, and continuous improving processes. TQM is a practice of continuous improvement through the repetition of Deming Cycle to detect and solve problems (Edward, 1996; Chizmar, 1994). The core characteristics of TQM include: (1) customer-orientation (Bensimon, 1995; Ewell, 1993; Kanji & Asher, 1995; Tsang & Antony, 2001), (2) promoting teamwork by a Quality Control Circle (Bonstingl, 1993; Chizmar, 1994; Kanji & Asher, 1995; Tsang & Antony, 2001), (3) continuous improvement by the "Plan-Do-Study-Action" (PDSA) (Deming, 1986; Kanji & Asher, 1995; Tsang & Antony, 2001), and (4) correctly reflecting upon the efficiency of progress.

TQM has been identified as an effective approach to enhance teamwork performance in education. Chizmar (1994) asserted that teaching strategy, integrating TQM, could elevate students' active learning attitude. Students should personally participate in projects, and accumulate experiences in the course. Dahlgaard, Kristensen and Kanji (1995) indicated that an educational culture with TQM is created by increasing customer satisfaction through continuous improvements, in which all staffs and students actively participate. TQM may promote PBL objectives achieving which includes the precut of learners' continuous self-evaluation and regular reflections upon whether or not to adjust the learning strategies (Blumenfeld et al., 1991). This loop of learning feedback will further foster the effectiveness of PBL groups collaborative learning (Krajcik et al., 1994; Lou & MacGregor, 2004).

According to the aforementioned studies, OPA supported by TQM is a beneficial tool which might not only cultivate students' spirits of continuous seeking improvement but also enhance their team work skills. TQM was grafted and integrated into OPA in the current study. this notion is also suitable for use with traditional peer assessment. The key assumption is that introducing TQM teamwork training and team management into the assessment process for capstone PBL may elevate learning performance.

To further inspire students' TQM spirit, the study introduced "continuous seeking improvement" into the OPA activity. This is done through the scoring formula used to assign grades. The principle involved can be illustrated with the following general formula.

Total Score= (*Final Score from Teacher*)x(W1) + (*Average Progressive Score of team project from all three-rounds of OPA*)x(W2)

Where Total Score=the final course grades; *Final Score from Teacher* = the final (the 3rd round) score that each group receives from their teacher on the assignment; this score was based on the ratings of all participating peer assessors feedback; W1 = the proportional weight that the teacher allocated to the *Final Score from Teacher*; *Average Progressive Score of our team project from all three-rounds of OPA* = the summation of the progressive score from all three-rounds OPA and then was divided by three; W2 = the proportional weight that the teacher allocated to the *Average Progressive Score of team project from all three-rounds of OPA*.

The formula comprised of two components: a "*Final Score from Teacher*" and an "*Average Progressive Score of team project from all three-rounds of OPA*." "*Final Score from Teacher*" is a score which is determined by teacher after assessing the 3rd round of group work for each group. The study included teacher's assessment as part of the total score because Wen & Tasi (2006) pointed out that most students preferred the PA scores to constitute a minor portion of the final score; none of the students favored total reliance merely on the PA score itself, and the responsibility of grading and summative evaluation should full upon the teacher's shoulders. The second component, *Average Progressive Score of team project from all three-rounds of OPA*, encompassed an essential factor, reward interdependence among team members, encouraging continuously improvement seeking. Moreover, reward interdependence prevented the reward system from being unidirectional (insiders only) and ensured

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diverse sources of feedback; team members of different abilities and traits were all given a channel to provide feedback, in cooperative a multidimensional evaluation interface.

Therefore, the purpose of the study was to introduce and examine the effectiveness of an innovative approach for PBL, named "OPA with TQM," which was designed to combat the aforementioned threats of PBL and enhance students' performance of PBL. The effectiveness of proposed OPA pedagogy were examined via an experiment. A total of 63 junior university students in their junior years in Taiwan voluntarily participated in this study and a two-group quasi-experimental approach, OPA with and without TQM treatment. The experiment design was a nonequivalent pretest-post-test control/comparison group approach with dependent variable being students' performance in OLED design concept, OLED design skills, and the attitude toward PBL, were evaluated to demonstrate the effects of "OPA with TQM" approach. The study attempted to address the following research issues.

1. The effectiveness of OPA with TQM approach in PBL upon students' OLED design concept.
2. The effectiveness of OPA with TQM approach in PBL upon students' OLED design skills.
3. The effectiveness of OPA with TQM approach in PBL upon students' attitude toward PBL.
4. Students' perception about the effect of OPA with TQM approach in PBL.

Based on the criteria for the design of constructivist learning environments (Honebein, 1996), the Constructivist Project-based Learning Environment Survey (CPLES) was developed to evaluate students' attitude toward PBL, and its construct and psychometric measures have been empirically validated (Chang, 2006; Chang et al., 2011). CPLES is conceptualized as having six facets: Inquiry learning, Reflective learning, Teamwork, Creative problem solving, Open-endedness, Authenticity.

Reviewing the existing literature relevant to the research purpose as foundations of this study, the hypotheses were elaborated as the following.

H1: OPA with TQM has a positive effect on students' design concept.
H2: OPA with TQM has a positive effect on students' design skills.
H3: OPA with TQM has a positive effect on students' attitude toward PBL.
H3-1: OPA with TQM has positive effect on students' Inquiry learning attitude.
H3-2: OPA with TQM has positive effect on students' Reflective learning attitude.
H3-3: OPA with TQM has positive effect on students' Teamwork attitude.
H3-4: OPA with TQM has positive effect on students' Creative problem solving attitude.
H3-5: OPA with TQM has positive effect on students' Open-endedness attitude.
H3-6: OPA with TQM has positive effect on students' Authenticity attitude.

Update, there is a dearth of studies dealing with the issue how OPA with TQM support worked in collaborative learning environments of PBL courses and students' perception about its effectiveness in PBL. It is hoped that the current study might unreal and fill this void. It is also expected that the result of this work might provide important reference and practical guidance for teachers.

Methodology of Research

Participants and the Experimental Setting

To examine the research hypotheses, a field experiment, a nonequivalent pre/post-test control/comparison group design, was conducted in an experimental physics course in the Physics program at a university in Taiwan. Figure 1 illustrated the experimental design. The independent variable focuses on two different approaches, "OPA with TQM" (with TQM support) and "OPA without TQM" (without TQM support).

63 undergraduate students in their junior years who were enrolled in the course were recruited in this study. Participants were assigned to the experiential and control group based on their own willingness and choice; 30 students voluntarily took part in the experimental group (with TQM treatment), while the rest of 33 joined control group (without TQM supported). Students were grouped into 14 project teams, with team size of four-to-five students for the pedagogical advantages of small-group learning (Springer, Stanne, & Donovan, 1999); For the purpose of experimentally evaluating the actual effects of OPA with TQM approach, a PA with TQM support activity was designed in this class. All 30 students in the experimental group completed all the steps in the procedure, and the experiment sessions were implemented for 8 weeks for each class.

In the study, a simulation software, APSYS, which was developed by the Crosslight Software, Inc. (2006), was adopted to develop students' professional skills in OLED design. Thanks to the merit of economy in time and cost saving, APSYS had served as an excellent candidate for to the implementation of PA.

The production of optical semiconductor devices requires repeated iterations of the steps in the design, of crystal growth and test to achieve the desired performance. This process could be very time-consuming and expensive. If the optimized design can be achieved by using simulation software before mass production, the time and cost required for the development of the devices can be markedly reduced by the elimination of unnecessary trial fabrications. By applying simulation software, the Industry–University Collaboration model has been successfully developed and implemented (Chang et al., 2011).

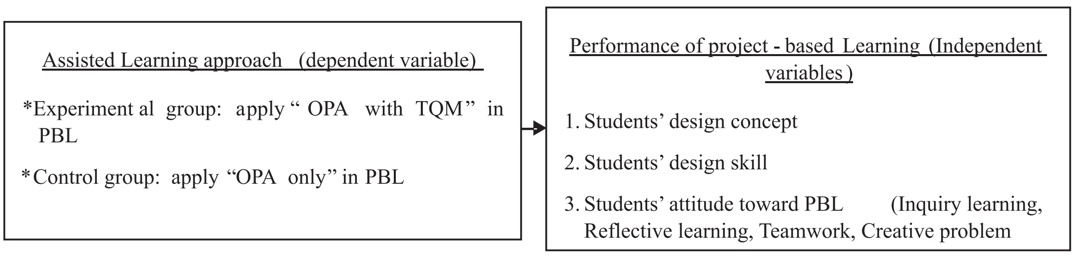

Figure 1: Research architecture.

Procedure and Treatment

Pretest for experimental and control groups

In the first two weeks, students in both the control and the experimental groups had same teacher and procedure. First, in the course orientation session, the professor explained the objectives and went through the syllabus of the proposed course as well as the requirement in completing the OLED design project. How to implement OPA and how to operate the simulation software were also explicated by the professor. The OPA procedure for both groups which included six steps were all elucidated to the students: (1) teacher introduced the assessment criteria of the OLED design project; (2) students upload the completed group assignments to the online assessment system; (3) professor assigned 3 peer group evaluators for each project; (4) group evaluators give grades and provide comments on the projects; (5) professor inform each groups of their grades and comments; (6) professor asked groups to make corrections or modifications based on the comments and group upload the modified assignment for an additional round of peer assessment.

Following the course orientation session, the professor introduced and explained basic OLED design knowledge including: basic structure of an OLED and its operating principles, OLED materials, the emission spectrum, the structure of quantum wells, internal quantum efficiency, spontaneous emission, and factors affecting OLED performance. A scaffolding example of how to improve OLED performance was demonstrated to both groups.

After the two-week sessions, to explore whether or not these two groups had similar antecedent knowledge level, a pretest exam of OLED design concept--were administered.

Experimental group

The instruction procedure for the experimental group included four steps.

Step 1. Collaborative skills training:

In order to enhance students' skills in collaboration team working, the experimental groups was instructed skills in communication, leadership and conflict management using the Deming Cycle instruction materials. The training material was versatile which integrated films about the Quality Control Circle and role plays, during the early stages of learning sessions.

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Step 2. Benchmark learning

In this step, a scaffold example of the Deming Cycle was demonstrated to students. The purpose of this intervention was to help students effectively modify their project to achieve better performance by comparing and assessing other group projects; then students can understand the difference between their work performance and better practices of others'.

Step 3. Checklist:

Whenever a new design was developed by others, the students were asked to discuss why the performance and parameters were different between their projects and the work of others'. This comparison was made through using of a scoring rubrics developed by Chang (2006). This rubrics stimulated students' reflective thinking upon what the differences were between these OLED designs and gave lights to which parameters needed to be adjusted to optimize OLED performance.

Step 4. Continuous improvement:

In each assessment, PDSA sequence was repeated at least twice. Students in the experimental groups were asked to discuss and review quantitative data and qualitative recommendations from other groups to identify relevant questions establish problem-solving strategies, and set goals for the next step.

Control group

Students in both the control group and the experimental groups had same curriculum, teacher, having taken the same courses in the project course. For the development of the projects, the project teams in the control group followed the ordinary OPA procedures as mentioned in the pretest step.

The project teams in the control group were also expected to work together to carry out the project, though they were not given any particular interventions of instructions to follow in this collaborative team projects. When students encountered problems, they sought out each other's help since collaboration was a requisite of this course. . In this situation, collaboration was transient and not formalized in the project teams.

The only difference between these two groups that students in the control group, were assessed only by "Final Scores from Teacher", unlike their experimental counterparts who undertook the "OPA with TQM" approach and the aforementioned scoring formula.

Post-test for experimental and control groups

Finally, students in both the control and experimental groups were given a post-test, to appraise their knowledge, skill, and attitude, after a three-round OPA.

Measurement and Data Analysis

Table 1 listed the study evaluation instruments in this experimental instruction, including knowledge maps, a photonics scoreboard, and the CPLES.

Table 1. Description of research measurement.

Objective of evaluation	Evaluation instruments	Description of the instruments
Knowledge	OLED design concept test	Examine students' understanding in OLED design concepts after the completion of projects
Skills	Photonics Scoreboard	Evaluate the OLED design skills by expert rating scores
Attitude	Constructivist Project-based Learning Environment Survey (CPLES) and in-depth interview	Examine students' attitudes toward the project-based learning environment developed by this study

To evaluate the effectiveness of the OPA with TQM approach in PBL, students' OLED design concepts, OLED design skills, and learning attitude were evaluated respectively by the OLED design concept test, a photonics scoreboard (Chang, 2006), and CPLES (Chang et al., 2011). The pretest and post-test in OLED design concept tests were applied to help evaluating students' understanding of the OLED design principles. The photonics scoreboard, built on an Internet platform, was adopted for peer and expert/teacher assessment. The CPLES was developed to investigate students' attitude toward the PBL environment (Chang, 2006; Chang et al., 2011). Students were asked to respond on a 5-point Likert-style scale (from 1 to 5) with 1 indicating "Strongly disagree" and 5 indicating "Strongly agree". Reliability analyses and exploratory factor analysis of the CPLES revealed that the Cronbach α for the whole instrument is over 0.95, and the amount of variance explained by factors was over 62% for each field test. these adequate psychometric properties demonstrated that CPLES was an appropriate measure for assess students' attitude.

To examine the effectiveness of the experiment, a series of t-tests was carried out to identify between and within group difference in the dependent variables. Results of the statistical analyses were illustrated in the following session.

Results of Research

Effect of OPA with TQM Approach on Students' Design Concept

Examining whether or not there was any between-group discrepancy in students' prior knowledge, an independent sample *t-test* was performed. As shown in Table 2, no significant difference was found between the experiment and control groups in their scores of OLED design concept (t=-1.225, p>0.05), implying that students in the two PBL groups had similar prior knowledge levels in OLED design concept.

Table 2. Result of t- test of the OLED design concept, comparing pretest for the two groups.

Group	N	Mean	SD	df	t value
OPA with TQM	30	47.60	12.891	61	-1.225
Only OPA	33	51.27	10.884		

A second independent sample t-test was conducted to examine the effectiveness of the experiment using participant's OLED design concept post-test scores as dependent variables. As demonstrated in Table 3, post-test scores of the two groups were not significantly different (t=-1.595, p>0.05). The results depicted that the OPA with TQM approach had no significant effect on students' OLED design concept.

Table 3. Result of *t* test in students' OLED design concept-post-test between group comparison.

Group	N	Mean	SD	df	t value
OPA with TQM	30	48.53	13.746	61	-1.595
Only OPA	33	53.18	9.129		

Influence of TQM on Students' OLED Design Skills

The expert rating scores (teacher's assessment scores) on the scoreboard for OLED projects were used to evaluate the effect on students' OLED design skills. Table 4 showed that these two groups had similar design skill levels (t=0.768, p>0.05).

Table 4. Results of *t* test in the 1st round scores of OLED design skills comparison of between-group post-test scores difference.

Groups	N	Mean	SD	df	t value
OPA with TQM	7	21.14	2.911	12	0.768
Only OPA	7	20.28	.488		

The 3rd t-test was carried out to test if students' OLED design skills differed in the 3rd round of teacher's evaluation. Results, as illustrated in Table 5, revealed that there was significant difference in students' 3rd round post-test scores ($t=3.10^{**}$, $p<0.01$). The results confirmed that the OPA with TQM group significantly outperformed in their OLED design skills based on the instructor's ratings.

Table 5. Results of *t* test in the 1st round scores of OLED design skills comparison of between-group post-test scores difference.

Groups	N	Mean	SD	df	t value
OPA with TQM	7	47.57	5.740	12	3.10**
PBL with only OPA	7	38.14	5.640		

Effect of OPA with TQM Approach on Students' Attitude toward the PBL Course

Results of comparison in the average scores as shown in Table 6 indicated that the average scores of two groups were between 3.51 and 4.12 (There was one invalid questionnaire in each group), i.e., most students expressed satisfaction about PBL course. Moreover, students in the experiment group had significant positive attitude toward PBL then their counterparts in the control group in the following dimensions: teamwork ($t=5.1$, $p<0.05$), and creative problem solving ($t=3.04$, $p<0.05$).

Table 6. t-test for students' attitude of the two groups toward the PBL course.

Subscales	Groups					
	OPA with TQM		OPA without TQM		t-test	
	N=29		N=32			
	M	S.D.	M	S.D.	t	p
Inquiry learning	3.66	0.48	3.51	0.56	1.11	.27
Reflective learning	3.82	0.40	3.69	0.47	1.19	.24
Teamwork	4.12	0.38	3.61	0.39	5.1	.00*
Creative problem solving	3.93	0.45	3.57	0.48	3.04	.00*
Open-endedness	3.64	0.75	3.64	0.55	.01	.98
Authenticity	3.52	0.62	3.51	0.59	.07	.94

Discussion

This study proposed an innovative approach, which incorporated OPA with TQM as a macro-level instructional method. The objectives of this research were to provide instructors who engaged in collaborative project learning with new alternative of guidance while they direct their students. It is also hoped that this study will give light to students' continuous improvement and the performance of Project-Based Learning in STEM courses can be elevate.

The results were presented as the following: (1) there was no significant difference in the leaning achievement in OLED design concept between the experimental and control groups. (2) for OLED design skills, the OPA with TQM group significantly outperformed the OPA-only group. (3) Compared with the OPA-only group, the teamwork and creative problem solving skills of the OPA-with-TQM group were significantly enhanced.

The results of the study provided valuable information and practical suggestions to PBL instructors; it also advanced the knowledge of group dynamics of PBL group project that helped to facilitate positive and productive teamwork, optimizing the effectiveness of PBL and student's learning outcome. However, there are two interesting findings that should be address further.

First, the proposed approach successfully enhanced university students' OLED design skills, yet this approach failed to achieve its goal in fostering students' design concept. Examining the mean scores of both the experimental and control groups, it is apparent that, though not significant, the control group even had higher scores both in the pre and post-test in OLED concept. Why did such a low score group (the experimental group) eventually performed significantly better in OLED design skills than their high-score counterparts? Qualitative information collected form interviewing the experimental group students provided some reasons for this question: "*S1-1 We made "smart guess" after assessing others' work via OPA*" "*S1-2 we deliberated why and how the other group designed that particular project and tried to imitate their viewpoints*" and "*S1-5 we adopted the trial-and-error strategy, sometimes it worked well.*" Learning by trying or doing appeared to be the reason why the experimental group outperformed the control group and the reasons might be that students in experimental group practiced their skills by knowing how to do instead of knowing why to do. Therefore, encouraging team–members to be responsible and excellent evaluators is of essential importance. Thus, it is suggested that the original scoring formula should be added a third component in sources of evaluation; the reward interdependence between assessor and assessees should be added to the proposed formula. The formula can be modified as follows.

Total Score = (*Final Scores from Teacher*)x(W1) + (*Average Progressive Scores of team from three-rounds of OPA*)x(W2) + (*Average Progressive Scores of other team which received our assessment comments from three-rounds of OPA*)x(W3)

Second, the proposed approach had relatively little and non-significant effect on inspiring students' attitude of inquiry learning and reflective learning. The course teacher pointed out that students would not spend much time to study this course further since this subject was not a required course for the entrance examination of graduate school. Students often concentrate on subjects relevant to the preparation of the entrance examination, their next stage life career development. Slavin (1990) and Sharan (1990) also found that a conventional exam-oriented education system produces negative effects on learning among junior undergraduate students.

These findings of the current study are slightly different from previous studies (Chizmar, 1994; Liu et al., 2001); however, there was no study exploring how OPA with TQM affected PBL in a STEM course. Chizmar (1994) showed that teaching strategy integrating TQM could enhance students' active learning attitude. Liu et al. (2001) pointed out that PA is helpful for undergraduate students, and students all show a positive attitude in regard to the proposed STEM course.

Conclusions and Limitations

An innovative PBL instructional approach, the OPA with TQM support approach, was proposed in the current study which provided an empirical investigation on its effectiveness on students' performance in an undergraduate STEM course. The particular design of this pedagogy is to tackle down some dilemmas that had been the downsides of PBL proven by previous studies such as insufficient communication, uneven distribution of tasks, and the free-rider problems so that the efficacy and quality of teamwork might be ensured. The results demonstrated that the team members after implementing the OPA with TQM approach tended to have better OLED design skill performance, efficient team-working and creative problem solving attitude. Thus, the proposed approach succeeded in facilitating team members to collaborate for seeking continuous improvement. However, this innovative PBL instructional method had no significant effect on enhancing students' design concept, inquiry learning and reflective learning attitude.

Data from in-depth interviews, serving as complement, indicated that for undergraduate junior students, OLED design was a brand new domain and it was difficult for them to finish the complicated projects in a short period of time. Some students might have used "smart guess" after assessing other team's work via OPA. Influence by the Confucian culture, Asian students respect their teachers as authority figures and usually over rely on books and teachers, whereas they had insufficient initiative and reflective thinking incentives. Therefore, elevating students' learning motivation for PBL regardless of pragmatic consideration of whether such subject is required for graduate school entrance exam for their pursuit of higher degrees is an important issue for higher education in Taiwan.

Although the current research adopted a rigorous research procedure, some limitations must be taken into consideration. Extrapolation of the results must be approached with cautions. Future studies are suggested to address the following issues. First, the findings and implications are obtained from merely one particular computer simulation software (i.e., APSYS); representativeness of the studied sample is limited since the sample size was not big. The implemented experimental instruction was a quasi experiment design, not based on strictly controls which paired up equivalent characteristics of individuals for comparison; Individual difference variables, such as personality, learning style, as well as group effect, such as group decision-making or team processes, could be incorporated in future studies. Second, the training course and procedure of TQM implementation could be standardized and computerized to progressively refine and sharpen the focus of peer judgments through discussion and reflection. Third, the students in Taiwan have unique value and behavioral patterns, such as they had diverse definition of learning achievement and diverse career pursuit. to be more inclusive of the target population that representative all walks undergraduate PBL and to be more confident of the research generalizability, cross-cultural validation studies using large sample is highly recommended.

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