在專題導向學習課程中探究學生的團隊歷程：採用團隊科學研究的觀點

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中文摘要

為了培養高中生的協作能力和團隊表現，以達到完成具有挑戰性的美國太空總署與美國國家太空協會合辦之「太空殖民專題競賽」專題報告書寫作的目標，身為科學教師的第一作者從 SciTS 的觀點設計了一門 PBL 課程，名為 Team Science and Project-Based Learning，簡稱為 TSPBL。在研究過程中，作者設計了一個評估學生團隊歷程相關表現的問卷，以更好地了解影響學生團隊合作的因素及其在 TSPBL 課程中的表現。課程結束後，七個參賽學生團隊中，三個團隊完成了他們的專題報告書，其中一隊的作品更獲得了 2019 年世界三等獎，是台灣唯一獲獎的隊伍。值得注意的是，STEM 教學有一種趨勢，即在團隊協作環境中設計或安排許多教學方法。然而，他們大多數傾向於關注在 STEM 內容知識和技能的獲得，而很少關注協作技能與團隊成效。因影響團隊成效的因素眾多且複雜，在研究和文章篇幅限制下，我們聚焦在學生能否完成全英文且跨領域之專題計畫書來代表其團隊成效。研究結果顯示，我們設計的團隊歷程問卷程說明了團隊氛圍和團隊效能這兩個研究因素可能在學生的團隊成效中發揮關鍵作用。在性別上，女生比起男生在團隊凝聚力與處理團隊衝突中，呈現統計上的顯著差異，扮演著正向的角色。TSPBL 課程和問卷似乎在科學教育的研究和實踐中具有潛在的應用。這項研究的結果有望幫助研究人員和學校教師了解團隊歷程的關鍵面向，提供有價值的建議做為課程設計指引，並能提升學生的科學協作技能和表現，增加國際專案競賽獲獎之機會。

關鍵詞：專題導向教學，團隊歷程，團隊科學研究

Investigating Students' Team Processes in a Project-Based Learning Course: From the Perspective of Science of Team Science

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Abstract

In order to enhance high school students' collaboration skills and team performance to achieve the goal of completing the challenging project report on the "Space Settlement Contest" co-organized by NASA and the National Space Society (NSS), the first author, who is a science teacher, has designed a PBL course with the perspective of SciTS called Team Science and Project-Based Learning, or TSPBL for short. Meanwhile, the authors designed an inventory to assess students' team process to better understand the factors that influence students' teamwork and their performance in TSPBL courses. After the course, three of the seven participating student teams completed their special reports, and one team's work won the 2019 World Third Prize, the only team in Taiwan to win. It is noticed that there is a trend of STEM instruction that many teaching approaches are designed or arranged in team collaboration settings. However, most of them tend to focus on the acquisition of STEM content knowledge and skills with little attention to collaborative skills and team effectiveness. Due to the numerous and complex factors that affect team effectiveness, under the limitations of research and space, we focus on the completion of students' all-English and cross-disciplinary project report to represent their team effectiveness. From results obtained in this study, it is noted that the Team Process Inventory we designed illustrates that two research factors, Team Climate and Team Efficacy, may play a key role in students' team effectiveness. In terms of gender, girls showed statistically significant differences compared with boys in Team Cohesion and Team Conflict resolving, and played a positive role. The TSPBL course and the inventory appear to have potential applications in the research and practice of science education. The results of this study are expected to help researchers and school teachers understand key aspects of team process, provide valuable advice to guide curriculum design, improve students' scientific collaboration skills and performance, and increase their chances of winning international project competitions.

Keywords： Project-Based Learning, Team Process, Science of Team Science

1. Introduction

In 2015, NRC presented a project report named as "Enhancing the Effectiveness of Team Science" to better inform an emerging field called the Science of Team Science (SciTS) that inquires the mechanics of the scientific collaboration among adult scientists. Meanwhile, the educational reform in Taiwan had been overwhelmingly implemented in order to cultivate students' core competencies. Core competence encompasses a combination of all the knowledge, skills, and attitudes that a person should possess to equip him or her for daily life and for tackling future challenges (Education, 2014). In view of the importance of interpersonal relationship and teamwork, it is realized that collaborative skills are crucial components of the core competencies, and that teachers are expected to help students develop these competencies (Wang, 2020) and broaden opportunities for all students. We need to redefine teaching and learning for the students of today and citizens of tomorrow on the path toward lifelong learning (Coudenys, Strohbach, Tang, & Udabe, 2022). Among a range of instructional approaches, Project-Based Learning (PBL), has been considered as an alternative approach to carry out the enhancement of core competencies (Baran, Maskan, & Yaşar, 2018). According to the new curriculum guidelines of the Ministry of Education, every school is expected to develop PBL courses as the school-required and elective courses to realize the orientation of the curriculum to the "real world" (教育部，2021).

However, current PBL approaches tend to focus primarily on students' acquisition of STEM knowledge and competencies with little attention to the factors of team process that affects the final team effectiveness. Team effectiveness (also referred to as team performance), according to the study of National Research Council, is defined as "A team's capacity to achieve its goals and objectives." In this study, completing multidisciplinary project entries (the goal of students' participation) is the criteria about their team effectiveness. Team processes are the underpinnings of team effectiveness (National Research Council, 2015). It suggested a relevant relationship between the team process and team effectiveness. Two phenomena deserve our attention:

First of all, the instructional implementation of secondary schools in Taiwan still over emphasizes on the teaching of a single subject. In order to meet the changing needs of the new generation and to develop students' ability in teamwork to solve complex problems in future life and career (Amoroso et al., 2021). traditional teaching inevitably confronts cross-disciplinary teaching challenge. To achieve the instructional goals of collaborative skills in STEM classroom, one of the appropriate instructional approaches may be PBL courses (Capraro, Capraro, & Morgan, 2013 2013). When it comes to 21st century skills such as communication, inquiry, presentation, time management, self-assessment, leadership, and group participation, PBL courses are proven to be an appropriate approach to achieve (Bell, 2010; Goodman & Stivers, 2010). It teaches students not just content knowledge, but also collaborative skills in ways students have to function well in our society. A carefully designed and well-implemented course is supposed to lead to effective classroom practices (Mergendoller & Thomas, 2003). While there are a few studies reported gains in students' interpersonal and teamwork skills (S. W. Kozlowski & Ilgen, 2006), the majority of research studies tend to focus on and overemphasize the cognitive learning outcomes of STEM instruction. Interpersonal and teamwork skills were seldom measured partly because of student's reluctance to evaluate peer's contributions to team's achievement (Falk-Krzesinski et al., 2011). Gender is reported as an important factor to affect team effectiveness and conflict resolving in some empirical studies (羅新興、林靜如，2007; Holt & DeVore, 2005). It is crucial to develop some recommendable ways to address this gap. In order to integrate the collaborative skills components into STEM instruction, the authors noticed that the principles and recommendations from the SciTS, although originally concerned with organizational research teams, offer useful guidelines toward reaching this goal.

Secondly, some research reports indicate that since the 1960s, the number of articles that were written by two or more authors has increased from 55% to more than 90%. The National Science Foundation values this phenomenon. At the request of NSF, National Research Council supported Nancy and other scholars to organize a Committee on the Science of Team Science. Scientific collaboration is clearly the mainstream of future academic development. Science of Team Science, abbreviated as SciTS, developed by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine Guidance and management. Its committee presented a project report in May 2015 named “Enhancing the Effectiveness of Team Science.” (National Research Council, 2015) In the 10-year literature review study between 2005 and 2015, the National Institutes of Health (NIH) has been convinced that team science is an important dimension in collaborative practice across disciplines. It can even help individuals and teams develop their future academic research careers and students' learning outcomes (Ambiyar & Afifah, 2019). The research components and perspectives could be considered as a significant tool to cultivate students' collaborative skills in PBL course. Besides, NASA and NSS, the administration of the space settlement contest, hope students' project entry to be creative, to surprise the judges, and to describe why you made the choices you did. However, there is numerous facets to reveal the details of mechanics of team process of student teams. Concerning the limitations of research, this study focuses on the completion of students' project reports to represent their team effectiveness regardless of the complex details in the process. In this study, the development and implementation of both a PBL course with the perspective of SciTS (abbreviated as TSPBL) and a team process inventory were significantly informed by the SciTS.

(1) Research Background

The duration of the TSPBL course is one semester from September 2018 to January 2019. One course session per week is about 100 minutes. The student teams separately working on their own projects aimed at participating an annual NASA Space Settlement Contest with various resources offered by the TSPBL course, including guidance and information provided by teachers with interdisciplinary expertise. In the process of the course, three science teachers and two experts in science education were invited into the course observe and provide some suggestions to exam the benefit of science content knowledge of the students. a selective course for grade 10~11 high school students. After the selection mechanism, there are 39 private high school students, with aged of 15-17 years old, formally participated in the TSPBL course and divided into 7 teams. The administration, NASA and NSS, hopes that teachers can make this contest part of their lesson plan or a cross curriculum project where science classes design the basic structure to support their students (https://space.nss.org/settlement/nasa/Contest).

As mentioned above, the goal of this TSPBL course is to engage students in experiencing the process of completing a multidisciplinary English-version 50-pages project report, and to enhance their collaborative skills and team performance so that they may have more opportunity to win the challenging award.

(2) Adopt SciTS Perspective into This Study

In the study of the science of team science (National Research Council, 2015) , it mentioned ten factors/components that affect team processes such as Team Climate, Team Cohesion, and Team Conflict, and so on. It is worth mentioning that the sequent component "Team Conflict" referred in our course and inventory means student's "capacity" to deal with the conflict within their team. All these factors listed above are known to inform the effectiveness of teamwork in the specific disciplinary: medical education, engineering, military, and flight security. However, by considering the research conditions and context of school education and culture, it appears that not all the components are equally important and relevant in this study. After numerous discussion and suggestion with experts in science education, initially we choose five components to develop a Team Process Inventory tentatively. In consideration of the school context and limitation in this study, it is necessary to filter out some inappropriate components in evaluating the effectiveness of students' collaboration. For examples, Team Mental Models, it is not easy to be understood by high school students without enough social experience. Transactive Memory is not so suitable for the students who study in the same classes and disciplinary areas at school. Team Process Competencies is far too complicated and challenging to design and implement in a typical class unit. After a pilot study and with further consideration about the limitation of the course, we highlighted the following five components: Team Climate, Team Cohesion, Team Efficacy, resolving Team Conflict (the capacity to deal with possible conflicts within a team), and Leadership (only for members to evaluate their team leader). Their definitions and descriptions are shown as Table 1.

Table 1 The adopted SciTS components and its descriptions/definitions

SciTS Components	Descriptions/Definitions
Team Climate	Team members shared perceptions about the strategic imperatives that guide the orientation and actions of team or group members. (Schneider & Reichers, 1983; Kozlowski & Hults, 1987)
Team Cohesion	It is multidimensional, with facets focused on task commitment, social relations, and group pride. (Beal et al., 2003)
Team Efficacy	In the individual level, research has established the important contribution of self-efficacy perceptions to goal accomplishment (Stajkovic & Luthans, 1988). Generalized to the team or organizational level, similar, shared perceptions are referred to as team efficacy (Bandura, 1977).
Team Conflict	Team or group conflict is a multidimensional construct with facets or relationship, task, and process conflicts. (de Wit, Greer, & Jehn, 2012, p.360)
Leadership	The main functions of leadership are to set direction, to align people, and to motivate and inspire them. (Kotter, 2001)

(3) Theoretical Framework

This study involves the collection of quantitative data mixed, to some extent, with qualitative interviews. This study intends to introduce SciTS perspectives to capture the process and the outcome of teamwork. In order to implement the SciTS perspectives, the design of TSPBL Course and the development of the Team Process Inventory adapted SciTS team process components to facilitate the development and assessment of students' collaboration skills. The conceptual framework of TSPBL Course is shown as Figure 1.

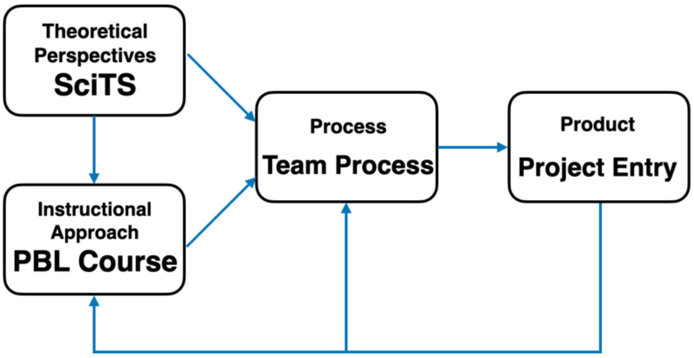


Figure 1 Conceptual Framework of TSPBL Course

(4) Research Questions

The TSPBL course aims to help not only the developments of students' STEM knowledge but also collaborative skills in the concerned research components. In order to better understand factors influencing students' team process and the performance of students' teamwork, we use the Team Process Inventory together with student interviews to collect and analyze relevant data. As explained earlier, regardless numerous complex factors affecting team effectiveness, we focus on the completion of students' project report in this study. It is also interesting to note that with regard to organizational role, male often use a forcing style in interpersonal interaction, while females are more likely to endorse the compromising attitude than males regardless of culture. (Holt & DeVore, 2005; Scherer & Petrick, 2001) In view of the above considerations, the research questions are as follows:

a. Is the TSPBL course designed in this study helpful for students in acquisition of science content knowledge through team scientific collaboration?

b. In terms of the completion of a project report, do teams with different performance levels have different scores, as indicated by Team Process Inventory, in the mid- and post-tests?

c. Are the scores of boys and girls different in the Team Process Inventory?

2. The Design and Implementation of a TSPBL Course

Some research reported that the middle school is an ideal time to integrate PBL course and a PBL course can shift the focus of teaching and learning from a set of known science knowledge to a process guided on the way that experts in the field think and work (Klein et al., 2009). This approach helps students achieve high levels of acquired knowledge and it has a positive effect on students' evaluation (Campos-Roca, 2021; Yang, 2021).

In terms of their preference in academic choice, the students are from both science- and social science-majored fields and vocational department shown as Table 2. This is the final date in the end of the course in consideration of that the number and composition of student teams still change until the date of mid-test. For example, Team 1 was formed by merging the other two small teams and became the largest team just before the mid-test. It took some time for them to be familiar each other teammate.

Table 2 Background of participants

Team	Number			Grade 10			Grade 11	
	Male	Female	Total	Social Science	Natural Science	Vocational Department	Social Science	Natural Science
1	5	4	9	0	0	0	5	4
2	4	3	7	0	0	0	3	4
3	0	5	5	0	0	0	2	3
4	4	1	5	0	0	0	4	1
5	4	0	4	4	0	0	0	0
6	3	2	5	3	2	0	0	0
7	3	1	4	0	0	4	0	0
Sum	23	16	39	7	2	4	14	12

The SciTS summarizes influencing factors on team process that have been shown to improve the effectiveness of teamwork (Fiscella, Mauksch, Bodenheimer, & Salas, 2017 & Salas, 2017). It is also an effective learning path of concept that allows a group of students to solve realistic and complex problems of daily life together for a common goal (Tupkalova & Todarchuk, 2019). Introducing the team process components suggested in SciTS, we designed the PBL course not only to facilitate high school students' STEM knowledge but also teach the collaborative skills. In project report writing, we design activity involved knowledge needed to complete three chapters in the Chinese-version project entries, such as artificial gravity (e.g., "Homopolar Motor" class). In collaborative capacity, we cultivate and strengthen students' willingness to remain together and maximize their team effectiveness (e.g., "River Hudson Miracle" class). Furthermore, we encourage students to achieve an English-version project report to be submitted to the international contest. Meanwhile, the process of designing a project report is thought as a suitable way to investigate students perception and their performance of learning (Hussain, Sahudin, Abu Samah, & Anuar, 2019 & Anuar, 2019). The details are discussed in the followings.

(1) Illustration of Selected Class Units in the Light of SciTS

Recent research shows that team science is an example of effective and impactful professional collaborative research practice (Little et al., 2017). The design of the science classes try to make the project-based experience more authentic and create some PBL challenges because that it is helpful to facilitate the development of students' essential skills beyond school (Laur, 2020). As an outline of our PBL course, Table 3 shows three selected class units to illustrate the selected SciTS components, activities, and brief descriptions. Each class, the first author adopted three components as the main instructional goals to design activities containing collaborative skills and scientific knowledge within about 60 minutes. Students have about 30 minutes to have heated discussions and 10 minutes to present their ideas for the peer evaluation and asking questions. After school, students keep their connection and collaboration in writing the project report. When they encounter some challenges that they cannot cope with, they ask for online-meetings with their teacher.

Table 3 The selected class units by selected SciTS components, activities, and descriptions

Class Units	Components	Activities	Descriptions
River Hudson Miracle	TC TCh TE	Take the aircraft landing incident as an example. Maximize team effectiveness.	Arrange pilots, air control center staff, tower staff, and other relevant officers if necessary. Simulate and demonstrate landing an airplane carried 153 passengers within 73 seconds on the Hudson River.
Bottle Cannon	TCh TE TCf	Prepare and launch bottles with a few alcohol with various conditions.	Team leaders allocate tasks, goals, rules, and observe the situation in which members interact with each other to reach the longest shooting distance.
Homopolar Motor	TC TCh TE	Simulating artificial gravity. Not only individual's effort, but also interaction between team members to make a prototype.	Through the experience of the activity in making homopolar motors, team members design, communicate and collaborate to simulate an environment with artificial fravity in outer space.

TC: Team Climate TCh: Team Cohesion TCf: Team Conflict TE: Team Efficacy

In order to make the TSPBL course more effective and helpful to students, the author invited two experts (doctors from National Changhua University of Education) and four peer teachers (sciences teachers in Taichung City) observed the course. Here are some commendations provided by them: (Tr: Teacher; Pf: Professor)

Tr2: "Most of the course content go along with the spirit of 'inquiry' and 'competence-oriented' teaching." (D3-20191126)

Pf1: "For a subject topic, as an example of the unit of "Artificial Gravity", the teacher provided open-ended exploration and discussion, and students really learn more than traditional teaching through brainstorming and collaboration." (D3-20191126)

Most of these teachers and experts appreciate and express the positive attitude to the alternative pedagogical method for the students in learning science content knowledge beyond traditional teaching.

(2) Six Instructional Steps in the Design of the TSPBL Course

Figure 2 shows the six steps for teachers in the design of the TSPBL course in this study. Each class unit gets started by giving the driving question (such as "How to simulate artificial gravity?") that may be the core problem in their space settlement project report. The following steps are: planning teaching content(circular motion, Newton's Second Law in Motion), arranging inquiry practice within 40 minutes (Homopolar Motor), demonstrating the project prototype as an sample for students (Initial project script), regulating the forms of students' presentation in reference (APA reference regulation), and using multiple forms of evaluation such as the teacher and peer's evaluation and feedback to their mind maps or presentations. With the 6-steps cycle, one topic after one, teachers might get a clearer picture in teaching both science content knowledge and enhancing their collaborative skills to help them finish their project reports.

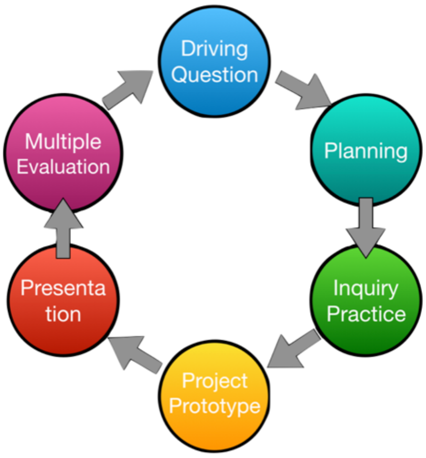


Figure 2 Six Instructional Steps in the TSPBL course

3. Development and Application of the Team Process Inventory

aligned with the same five SciTS components after a pilot study. Herein, we performed latent effectiveness of the application with Team Process Inventory while the TSPBL course proceeds. Not only quantitative analysis examines the course, but also qualitative interview responds the feedback to the course. With the comments of experts in science education as a triangulation, we hope to increase the generalization of this study’s outcome.

(1) Pilot Study

According to the adopted five SciTS components in the TSPBL course design, we developed and formed Team Process Inventory in the same perspectives. Because of seldom measure to investigate the understanding of students’ acquisition about collaboration skills(Dietz et al., 2014), since 2017, the first author attempted to use PBL as a student-centered approach to prepare students to do innovative research in multidisciplinary team learning (Schaffer, Chen, Zhu, & Oakes, 2012 & Oakes, 2012). The researchers collected, selected, translated, and revised the following questionnaires: TeamSTEPPS (Defense & Quality, 2016), Team Decision Making Questionnaire(Batorowicz & Shepherd, 2008), and Team Performance Survey (Salas, 2016). A preliminary version of the Team Process Inventory was examined and modified by three experts in science education and then was pilot-tested with a cohort of high school students (the same department in the same school) who had completed the TSPBL course offered by the first author. Data collected from 232 high school students’ effective questionnaires was analyzed before the beginning of this formal study. Research components are reduced from 50 items to 20 items. Representative items and their corresponding SciTS components are shown in Table 4. Consequently, with results obtained from the pilot study, the authors selected the five critical components mentioned above to form the Team Process Inventory that includes 16 items with 0-6 Likert scale scoring in 4 SciTS components. In order to investigate the leadership of students’ teams, 4 items of Leadership are additional just for members but not for leaders of student teams. It formed our Team Process Inventory in 5 categories and 20 items as the main tool to investigate the team process of student teams.

Table 4 Selected items and its correspondent components of Team Process Inventory

No.	Questionnaire Contents	Components
2	I can express my thoughts very freely.	Team Climate
8	Our team members collaboratively work together.	Team Cohesion
11	Members of the team can give constructive feedback.	Team Efficacy
16	Members of the team respect each other’s different perspectives.	Team Conflict
18	My team leader has been coaching and supporting each team members.	Leadership

Results from explanatory factor analysis of the pilot study are shown in Table 5. It indicates clear grouping of the 16 questionnaire items into four factors, namely, Team Climate, Team Cohesion, Team Efficacy, and Team Conflict (resolving capacity).

Table 5 The EFA of pilot study in Team Process Inventory in method Varimax

	SciTS Components			
No.	Team Cohesion	Team Conflict	Team Climate	Team Efficacy
5	0.812			
6	0.790			
8	0.763			
7	0.748			
15		0.814		
14		0.778		
16		0.699		
13		0.674		
3			0.854	
4			0.798	
2			0.727	
1			0.612	
10				0.735
11				0.733
9				0.671
12				0.658

(2) Applications of Team Process Inventory and Students Interviews

As the PBL course was delivered in this study, the Inventory was concurrently administered to the participating students at 3 stages that took place in October, November and December. The participating students reported their opinions about their team works through the Inventory on the website after taking a few class units. It turned out that the overall reliability of the Team Process Inventory was very good, with Cronbach's α values: .95, .96 and .96, for the pre-test, mid-test, and posttest respectively. In the middle and end of the semester, randomly selected students are interviewed with the semi-structural method. Each time the interview is about 10-15 minutes to ensure students can fully express their gains, feedback, and suggestions about the course. The quantitative data, the results of Team Process Inventory, indicates the components that effect students' team effectiveness. The qualitative data, students' feedback, are used to provide an explanation to the components in Team Process Inventory.

4. Results and Discussions

In the end of the TSPBL course, there are three teams (Team 1, 2, 3) completed English-version project entries and achieved the goal of the competition, then successfully submitted their reports to NASA, finally one team (Team 1) won the third prize in the world. Three teams (Team 4, 5, 6) finished Chinese-English mixed version proposals but not within the deadline required by NASA. On the contrary, one team (Team 7) fell apart and did little in their project. Mentioned above can be presented as Table 6.

Table 6 The Performance Level and Rubric Description of Student Teams

Performance	Levels	Student Teams	Rubric Descriptions
A	A1	Team 1	Student team can complete the multidisciplinary project report (at least 50 pages) in English version through collaboration on time, and win the worldwide prize.
	A2	Team 2&3	Student team can complete the multidisciplinary project report (at least 50 pages) in English version through collaboration on time.
B	B1	Team 4&5	Student team can complete the multidisciplinary project report (at least 50 pages) in English version through collaboration, but not on time
	B2	Team 6	Student team can write the prototype multidisciplinary project report (at least 3 chapters) in mixed version (Chinese & English) through collaboration, but not on time
C	C	Team 7	Student team fall apart and cannot keep any function of their team, unable to present any report.

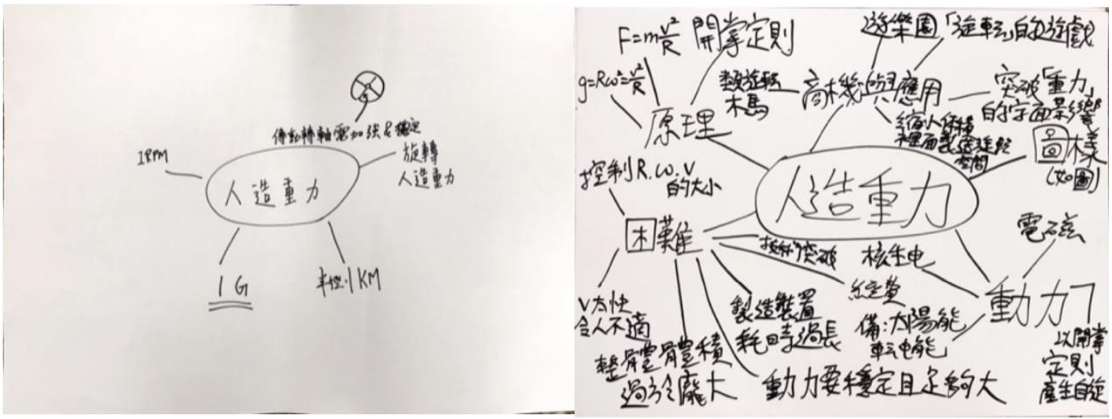
The three levels of student teams' final performance clearly indicate the wide variations among them after taking this TSPBL course. All the participant students acquired abundant science content knowledge in collaboration. Three student teams in Level A (Team 1, 2, and 3) of seven teams in total achieved the goal of completing their interdisciplinary project reports through collaboration on time. Furthermore, Team 1 on Level A1 shown their excellent team effectiveness and won the third prize in the world in 2019. Quantitative and qualitative data will be analyzed to interpret the differences of the results of student teams' performance.

(1) Acquisition of Science Content Knowledge Through the TSPBL Course

Through a series of semi-structural interviews, many students made comments on the concerned components of Team Process. From their remarks, it can be captured some significant information about students' effectiveness of learning. The TSPBL course, compared to traditional methodologies, indeed offered an appropriate environment to motivate them more and to think more creatively in developing important concepts. Under such learning situation, they recognized the importance of the nature of team, such as Team Climate and Team Efficacy. Through better collaborative skills, students have more opportunities into deep and active learning than they study alone. Take an example, one student served as a team leader shared his feedback in the face-to-face interview,

> T1-S1: “I think the TSPBL course had made me much more engaged in learning science. In the past, I often felt bored in the regular classes, and might just think that the team is just a few people doing one thing together. After a few classes in PBL course, I knew that the team must be one entity to complement each other's shortcomings and advantages, and then take turns to assume the role of leadership, and so on. With the power of collaboration in learning, we fully exert the spirit of the team and try to maximize the team efficiency of our team in a comfortable climate. For me, I learned more effectively. For my team, the course made me believe that we can achieve the project creatively.” (C9-20191224)

Similar to what was found by Frontera & Rodriguez-Seda (Frontera & Rodriguez-Seda, 2021), the participant students claimed that they acquired disciplinary content knowledge through the PBL course. With appropriate team collaboration, they learned more effectively because PBL can enhance students’ attention of learning outcomes. Take the topic “Artificial Gravity” as an example, it indicated the development and complexity of students’ STEM knowledge in their mind map shown as Figure 3.



Students’ Mind Map Before PBL Course　　Students’ Mind Map After PBL Course

Figure 3 The mind maps of students before- and after-intervention of PBL course

(2) Complete the Project or Not? SciTS-Based Components Make a Difference.

It is really a challenging task for Taiwan high school students to achieve such a comprehensive (50 pages), multi-disciplinary (including almost natural science and human science subject knowledge), and English-version (because of that it is not their native language and some obscure terminologies) space settlement project entry. As shown in Table 6. Three teams reaching performance level A (Team 1, Team 2, and Team 3, 21 students in total) had achieved the goal of the TSPBL course and completed their project entries and, furthermore, one team (Team 1) won the worldwide third prize honorably. However, there are four teams with performance levels B and C (Team 4, Team 5, Team 6, and Team 7, 18 students in total) did not complete their project reports in English on time. Team 7, even worse, fell apart and failed in team effectiveness. It's interesting to compare student teams' average scores on the Team Process Inventory between the teams that successfully completed their project entries in English and the other teams that did not. Results obtained from this study indicated that student teams' average scores in the Team Process Inventory seem play a crucial role in students' scientific collaboration close related to the completion of their projects. As shown as Table 7, in posttest, all the five components presented a significantly statistically significant difference (about $p<0.05$) between the teams that completed the projects and the teams that didn't.

Table 7 The t-test of student teams in Performance Level A, B, and C in posttest in the five components

Components	Performance Levels A: Team 1, 2, 3 B&C: Team 4, 5, 6, 7	Size	M(SD)	t	p
Team Climate	A	21	5.60(0.51)	2.04	<.05
	B&C	18	5.23(0.62)		
Team Cohesion	A	21	5.73(0.46)	1.81	<.05
	B&C	18	5.39(0.67)		
Team Efficacy	A	21	5.40(0.63)	2.01	<.05
	B&C	18	4.97(0.71)		
Team Conflict	A	21	5.73(0.46)	2.60	<.05
	B&C	18	5.26(0.63)		
Leadership	A	21	5.60(0.51)	2.42	<.05
	B&C	18	5.03(0.84)		

(3) The Improvement in Team Climate, Team Efficacy, and Leadership in the Process Characterized the Awarded Student Team

Team 1 (9 students), received the world-class awards (the third prize) among 2,691 entries involving 12,899 students in the world (https://space.nss.org/settlement/nasa/Contest/Results/2019/index.html). Retrospection of their performance based on the mid- and post-tests team process scores as shown in Table 8 is given as follows. The reason not to take the result of pre-test is that student members is changing (join, quit, and reorganize) until the date of mid-test.

Table 8 The t-test for the difference between mid- and post-tests among student teams having been awarded or not.

Components	Performance Levels	Size	M(SD)		t	p	
			Mid-test	Post-test			
Team Climate	A1 (Team 1)	9	4.75(0.59)	5.40(0.25)	2.02		<.05
	A2~C (Others)	30	5.12(0.78)	5.32(0.61)	2.52	0.22	
Team Cohesion	A1 (Team 1)	9	5.33(0.61)	5.35(0.46)	2.93	0.96	
	A2~C (Others)	30	5.59(0.74)	5.51(0.64)	2.74	0.58	
Team Efficacy	A1 (Team 1)	9	4.67(0.20)	5.25(0.35)	2.05		<.05
	A2~C (Others)	30	5.29(0.81)	5.07(0.72)	2.46	0.18	
Team Conflict	A1 (Team 1)	9	5.46(0.29)	5.45(0.33)	2.94	0.97	
	A2~C (Others)	30	5.39(0.67)	5.39(0.63)	2.98	1.00	
Leadership	A1 (Team 1)	9	4.75(0.42)	5.15(0.34)	2.45	0.18	
	A2~C (Others)	30	5.27(0.67)	5.22(0.82)	2.80	0.70	

The awarded team (Team 1), as mentioned before, is the largest team formed by two small teams before the mid-test. According the author's (their science teacher) observation, they initially feel not so comfortable in the team climate and their discussion as other teams. It might lead to the significantly lower scores in components of Team Climate, Team Efficacy, and Leadership compared to other teams' in mid-test. But if we focus on the trend of the scores of the two components, Team Climate and Team Efficacy,–their post-test scores (5.40 & 5.25) are both statistically higher (at $p<0.05$) than the mid-test scores (4.75 & 4.67). In addition, the awarded team's score of the component of Team Leadership increased from mid-test (4.75) to post-test (5.15). Although the difference does not reach the statistically significant criteria, it still represents a noticeable increase. On the contrary, for the other unawarded teams there is no significant difference between the post- and mid-test scores in all the five components shown as Table 8.

As qualitative data shown below, it appears that something special concerning Team Climate and Team Efficacy might have happened to Team 1 during the latter part of the semester. Students' feedbacks of the awarded team obviously meet the definitions of components of Team Climate and Team efficacy shown as Table 1. They shared their perceptions about the strategic imperatives that guide the orientation and actions of team (Team Climate), and expressed their self-efficacy perceptions to goal accomplishment (Team Efficacy).

Students of the awarded Team 1 shared their feedback in semi-structural interview described as the followings:

T1-S3: "What I learned most in this course was how to communicate with peers, how to cooperate, and how to find information. In the later stage of the course, I think everyone has a common idea, we must do our best to complete the project..." (Team Climate) (C9-20191224)

T1-S5: "This course trained me how to integrate the advantages of each person, and maximize and optimize this project. I think we should be able to finish the project on time... others feel the same way…" (Team Efficacy) (C9-20191224)

On the other hand, other unawarded students shared their feedback that follows:

T7-S4: "When I first joined this course, I hoped to learn a lot of space knowledge, because I was interested in this field, which is why I joined this course. After I actually entered the team operation, I felt that everyone's collective goals were not so clear, that is, everyone didn't want to be so determined, and I didn't have so much time to invest myself to the project, so I decided to quit." (C10-20191231)

T7-S2: "The course is good. It is none of the business about the course. I don't think everyone on the team is very interested in this. So, the efficiency is not as good as expected. And from then on, I felt it was unlikely that we would hand over a proposal in January. "(C10-20191231)

In comparison, the students who did not win the prize showed less perception in team collaboration. They focused on themselves more than others in the team in consideration of their personal benefit. Although they affirmed the contribution of the course, they were not confident to achieve the goal of completing the project report on time. Especially in Team Climate and Team Efficacy, there is almost no positive remarks appeared in their feedback according to the definitions.

To sum up, it appears that the improvement in Team Climate, Team Efficacy, and Leadership during the TSPBL course seem to have played a crucial role to help Team 1 students to be awarded by NASA and NSS. However, in consideration of the limitation of the number and diversity of students involved in this study, and other influencing factors, further research studies are needed in order to figure out the details as how to successfully complete a project report and win an international award.

(4) Female got Higher Scores than Male in Team Cohesion and Team Conflict.

As shown in Table 9, female students tend to score higher than male students in their posttest scores across all the five SciTS components. Especially, in terms of Team

Cohesion and Team Conflict, the statistically significant differences in t-test appear between male and female student team members. The findings are consistent with results mentioned in Holt & DeVore (2005), and are expected to have potential implications for improving team process performance.

Table 9 The t-test of the male and female members in the posttest in the SciTS components

Components	1: Male 0: Female	Size	M(SD)	t	p
Team Climate	1	23	5.22(0.64)	2.85	0.09
	0	16	5.53(0.51)		
Team Cohesion	1	23	5.33(0.68)	2.01	<.05
	0	16	5.74(0.45)		
Team Efficacy	1	23	4.96(0.74)	2.86	0.10
	0	16	5.32(0.67)		
Team Conflict	1	23	5.19(0.62)	2.02	<.05
	0	16	5.74(0.45)		
Leadership	1	23	5.07(0.78)	2.98	0.14
	0	16	5.42(0.77)		

(5) The leader of Team 3 (5 female members) shared her feedback:

T3-S1: “I am very grateful to my team members, everyone is so responsible, I am so happy that I can find such a great team! I am proud of them.” (Team Cohesion) (C11-20200107)

T3-S1: “When I want to type to someone on Messenger, I will first think about it, should I write this way? I will still hesitate and take care of another people's mood more than when I speak. So, it seems that because of this, there will be less conflict. I think that the other team members should have the same thought!” (Avoiding Team Conflict) (C11-20200107)

T3-S1: “The reason may be because everyone is willing to accept each other's ideas. We are also willing to discuss, so it is easy to put all the ideas together, and then dissolve them. So, we resolved a lot of conflicts.” (Resolving Team Conflict &Team Cohesion) (C11-20200107)

5. Conclusions and Suggestions

The TSPBL course, designed in PBL framework of instruction with the SciTS components, not only help high school student teams to acquire science content knowledge, but also cultivate their collaborative skills. We take student team’s completion of project report as team effectiveness to distinguish their performance levels shown as Table 6. In the view of students’ final performance levels, the Level

A1&A2 student teams (Team 1, 2, and 3) successfully achieve the goal of completing the NASA requirement in the space settlement contest. It is worth mentioning that Level A1 (Team 1) won the worldwide third prize in 2019, and they were the only one team from Taiwan. This course does give contribution to encourage students' confidence and engage them in scientific collaboration. Not only team members of Level A1&A2 confirms the effectiveness of the TSPBL course, but also the students of Level B1, B2, and C give their positive evaluation to the course. In the face of the huge, multidisciplinary, and challenging project, high school students need not only traditional instruction to science content knowledge but also systematically regulated 6-steps TSPBL course to guide and assist. With the fulfillment of team effectiveness, they actually have more opportunity to complete the project entry and even to win the worldwide prize. Three experts in science education and peer science teachers have consistently shown their positive attitudes toward the contribution of the TSPBL course.

The Team Process Inventory that is developed along with the TSPBL course has given a predictive contribution to student teams performance. In the posttest, the Level A teams get statistically significant higher scores than the Level B and C teams in all the five SciTS components, indicating the fact that all the five SciTS components are important for student teams to achieve the goal of completing the project reports. According the result of the analysis of quantitative and qualitative data, the developed collaborative skills is needed for students to enhancing their team effectiveness. Besides this, it appears that the improvement in Team Climate, Team Efficacy, and Leadership during the TSPBL course seem to have played a crucial role for Team 1 students to win a prize in an international contest.

The performance of female members in the Team Cohesion and Team Conflict components in posttest might imply that female members are more willing to pay attention to focus on team pride, social relationship, and task commitment(Batorowicz & Shepherd, 2008) than male members, and describes that girls in their teams seems have a better capacity to resolve relationship, task, and process conflicts (de Wit, Greer, & Jehn, 2011 2011) than boys. It might be an alternative to reduce the opportunity of the happening of conflicts in teamwork by appropriately increasing the percentage of female members. Besides, the leader of student teams certainly need to set the direction, align and inspire their members (Kotter, 2017) to have a better performance in the contest.An adaptive perspective in SciTS to develop a PBL course (TSPBL course) and to regulate and apply the Team Process Inventory is feasible and acceptable. In Short, TSPBL teaches high school student scientific collaboration, and Team Process Inventory identifies its functioning. It really works to enhance team effectiveness of high school student teams in completing multidisciplinary project entries just like the study on adult experts presented by NRC in 2015 (National Research Council, 2015). However, TSPBL need longer time to apply and more diverse students to modify its content. And also, there are still numerous facets and factors (e.g., the culture of school, the support from families) to affect team effectiveness not just the completion of project report. In response to the request of the cultivation of core competence and make up the lack of collaborative skills in STEM classroom, the TSPBL course and Team Process Inventory are potentially very recommendable.

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