INTERACTION OF SCIENTIST-TEACHER-STUDENTS IN PROBLEM-PROJECT BASED LEARNING

CHEONG BOON YAU

FACULTY OF EDUCATION
UNIVERSITY OF MALAYA
KUALA LUMPUR

2021

INTERACTION OF SCIENTIST-TEACHER-STUDENTS IN PROBLEM-PROJECT BASED LEARNING

CHEONG BOON YAU

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF EDUCATION (SCIENCE EDUCATION)

FACULTY OF EDUCATION
UNIVERSITY OF MALAYA
KUALA LUMPUR

2021

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: **CHEONG BOON YAU**

Matric No: **POC170002**

Name of Degree: **MASTER OF EDUCATION (SCIENCE EDUCATION)** Title of Dissertation ("this Work"):

INTERACTION OF SCIENTIST-TEACHER-STUDENTS IN PROBLEM-PROJECT BASED LEARNING

Field of Study: **INTERACTIONISM IN SCIENCE EDUCATION**

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date: 01.04.2021

Subscribed and solemnly declared before,

Witness's Signature Date:01.04.2021

Name:

Designation:

INTERACTION OF SCIENTIST-TEACHER-STUDENTS IN PROBLEM-PROJECT BASED LEARNING

ABSTRACT

Inviting scientist into inquiry-based learning has become the puzzles to be addressed in science education. However, finite mechanism on how tripartite interaction between scientist, teacher and students takes place is yet to be explored. This study sheds light on interaction of scientist-teacher-students collaboration in problem-project based learning (STSC-PPbl) in authentic research setting. This basic qualitative-exploratory study employed participant observation protocol triangulated by reflective journals written by students to collect the data of interaction between one scientist, one teacher and four upper secondary school students in this study. The data were analysed qualitatively using Balesian Interaction Process Analysis (IPA) coupled with adapted Transcript Analysis Tool and the structural elements of interaction were analysed using Structural Exchange Pattern (SEP) analysis based on quantification of qualitative codes. SEP analysis showed that students could have direct interaction with scientist. The findings from IPA revealed variety of interaction functions of scientist, teacher, and students from orientation, control, evaluation and independency in neutral task areas; decision, integration and tension management in socioemotional areas during variety modes of interactions. All these interactions reflected the role of scientist as scientific practice expertise, and teacher as education practitioner and facilitator associated with neutral task area functions as "one teaches, one assists and facilitates" co-teaching duo. The findings from socioemotional areas revealed that students showed remarkable intensity of negative tension management functions due to problems faced during experimentation and it can be resolved by tension release and integration functions executed by both scientist and teacher. This study suggests that educators can view and make tension aroused within students as the trigger and driver of science learning facilitation through employing appropriate interactive strategies based on the findings from this study to make such collaboration meaningful and successful, devising interactive strategy implementation for school-industry partnership from science education perspective.

Keywords: scientist-teacher-students collaboration, problem-project based learning, interaction process analysis, structural exchange pattern

INTERAKSI SAINTIS-GURU-PELAJAR DALAM PEMBELAJARAN BERASASKAN MASALAH-PROJEK

ABSTRAK

Pelawaan saintis ke pembelajaran berasaskan inkuiri merupakan suatu isu yang perlu disampaikan dalam pendidikan sains. Namun begitu, mekanisme untuk menggambarkan bagaimana interaksi antara tiga pihak termasuk saintis, guru dan pelajar berlaku sememangnya terhad dan perlu dieksplor. Kajian ini bertujuan untuk mengkaji interaksi sewaktu kolaborasi saintis-guru-pelajar dalam pembelajaran berasaskan masalah-projek (STSC-PPbl) dalam konteks penyelidikan sebenar. Kajian kualitatif-eksploratori menggunakan pemerhatian dari sudut peserta dengan triangulasi jurnal reflektif oleh pelajar untuk menggumpul data berkaitan dengan interaksi antara seorang saintis, seorang guru dan empat orang pelajar menengah atas. Data terkumpul dianalisis secara kualitatif dengan menggunakan analisa proses interaksi (IPA) berpadankan Alat Analisis Transkrip (TAT) manakala unsur struktur interaksi dianalisis dengan dengan menggunakan analisis corak pertukaran struktur (SEP) berdasarkan pengukuran kod qualitatif secara quantitatif. SEP menunjukkan bahawa pelajar mendapat peluang untuk berinteraksi dengan saintis secara terus. Dapatan kajian IPA menunjukkan kepelbagaian fungsi interaksi yang dimainkan oleh saintis, guru dan pelajar dari segi orientasi, perkawalan, penilaian dan berdikari dalam bidang tugasan neutral; manakala keputusan, integrasi dan pengurusan ketegangan dalam bidang sosioemosi sepanjang pelbagai mod interaksi. Kesemua interaksi memaparkan peranan saintis sebagai pakar amalan saintifik dan guru sebagai pengamal pendidikan dan fasilitator berhubung dengan fungsi interaksi bidang tugasan neutral sebagai pasangan pengajar bersama dalam bentuk "seorang mengajar, seorang membantu dan memudahkan". Dapatan kajian dari bidang sosioemosi menunjukkan intensiti luar biasa pelajar dalam fungsi pengurusan ketegangan secara negatif atas sebab masalah dihadapi sepanjang proses eksperimen dan ia boleh diselesaikan dengan fungsi pelepasan ketegangan dan integrasi yang dimainkan oleh saintis dan guru. Kajian ini mencadangkan pendidik melihat dan menjadikan ketegangan murid sebagai pencetus dan pendorong pemudahcaraan pembelajaran sains dengan menggunakan strategi interaksi yang sesuai berdasarkan dapatan kajian ini untuk menjayakan kolaborasi ini dengan bermakna, serta mengeluarkan pelaksanaan strategi yang interaktif untuk perkongsian sekolah-industri dari perspektif pendidikan sains.

Kata kunci: kolaborasi saintis-guru-pelajar, pembelajaran berasaskan masalah-projek, analisa proses interaksi, corak pertukaran struktur

ACKNOWLEDGEMENTS

First and foremost, I wish to express my deepest gratitude to God for His consent and blessings, without Him I would not be able to complete this Master of Education successfully, as well as enduring each hardship with perseverance.

Next, I would like to show my profound thankfulness to my dearest supervisor, Associate Prof. Dr. Rose Amnah Abd Rauf, for her motivations, guidance, and untiring contributions throughout this research. She guided me with lots of caring and patience, providing me ample of useful comments. Thank you so much Dr. Rose, you are the one that grew me from nothing to something.

I am so grateful to all other lecturers of Department of Mathematics and Science Education, Faculty of Education, for their generous assistance and useful advices throughout this research and journey of study. They provided me a lot of valuable guidance and information on research conduction and dissertation writing.

In addition, I would like to extend my gratitude to board of directors and school administrators of Chong Hwa Independent High School, Kuala Lumpur for providing me 80% scholarship to pursue my master's degree and funded my research project. Their continuous support has pushed me a step forward to achieve my milestone in my life, a pathway to be a science educator with continuum of professional development.

High appreciation I would like to express to Forest Research Institute Malaysia (FRIM) for providing experts to take part in this study. This is the very first meaningful collaboration fostered between a secondary school and a research institute that I participated in as one of the initiatives to bridge the gap in reforming science education.

On a personal level I would like to address my appreciation to my beloved mother, Madam Chew Ai Wah and my both lovely siblings, Cheong Lih Wen and Cheong Li Yan. Family is always the greatest motivator for me to go through every stages of life.

Last but not least, to my late father in the heaven, Mr. Cheong Kien Kok, thanks for your love too.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Expansion
3R’s	Recycling, reducing, and reusing
b.h.	Behavioral response
CL	Collaborative learning
CUPRAC	Cupric reducing antioxidant capacity
DPPH	2,2-diphenyl-1-picrylhydrazyl
f.	Experiential feeling
f.e.	Facial expression
IBE	Inquiry based instruction
IPA	Interaction Process Analysis
IR4.0	Fourth Industrial Revolution
KBSM	Kurikulum Bersepadu Sekolah Menengah
MKO	More Knowledgeable Others
MoE	Ministry of Education
MTT	3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide
PbBL	Problem based learning
PjBL	Project based learning
PPbl	Problem-project based learning
PPE	Personal protective equipment
Rotavap	Rotatory evaporator
SEP	Structural exchange pattern
STEM	Science, Technology, Engineering and Mathematics
STS	Scientist-teacher-students
STSC	Scientist-teacher-students collaboration

STSC-PPbl	Scientist-teacher-students collaboration in problem-project based learning
TAT	Transcript Analysis Tools
WEF	World Economic Forum
ZPD	Zone of Proximal Development

LIST OF APPENDICES

LIST OF EQUATIONS

LIST OF AWARDS

Gold Medal, Innovative Practices in Education Expo (IPEX) 2018 (International)

Cheong Boon Yau (Project Leader), Rose Amnah Abd Rauf, Tan Poh Poh, Ong Huey Jiuan, Chin Chen Fong

Title of Innovation and Extended Abstract: "Scientist-Teacher-Students Collaboration in Science PBL: A Gift from Science Education Reform in a Secondary School"

Project Fund: Chong Hwa Independent High School, Kuala Lumpur

Bronze Medal, Congress of Teaching and Learning Innovation (K-NOVASI) 2020 (National)

Cheong Boon Yau (Project Leader), Rose Amnah Abd Rauf, Shalini Markandan

Title of Innovation and Extended Abstract: "Scientist-Teacher-Students Collaboration in Problem-Project Based Learning: A Meaningful Approach for Authentic Science Learning"

Project Fund: Chong Hwa Independent High School, Kuala Lumpur

LIST OF PUBLICATION AND CONFERENCE DURING CANDIDATURE

Cheong Boon Yau & Rose Amnah Abd Rauf, Conceptual and Theoretical Framework of Learning Molecular Geometry using Metacognitive Strategies, Paper presented in International Science, Technology, Engineering and Mathematics (ICSTEM), Kuala Lumpur, Malaysia, 2-4 October 2018 (International)

CHAPTER 1: INTRODUCTION

1.1 Introduction

We are in the precipice of the Fourth Industrial Revolution (IR4.0), which is the era of dramatic change with exponential growth of science and technological advancements. Industry and school must ask the questions about how both parties work synergistically to prepare present and future generations to thrive in this transforming world, especially in the field of science education. One of the puzzles needs to be addressed is to prepare students to experience the world of careers, particularly the emerging careers in the future, before they leave the school. It is significant to enable school-to-works transitions through industry-school partnership (Torri, 2018) as revealed in the report below:

> *Partnership activities provide rich real-world learning opportunities that spark students' curiosity, and open students to a range of new and emerging professions. Activities are linked to improved engagement in learning and support the development of capabilities critical to the future of work, including problem solving, collaboration, enhanced STEM skills, digital literacy skills, and entrepreneurial mindsets. ... The knowledge-sharing that occurs between teachers and industry professionals also supports teachers to provide more innovative and enriched learning.* (Torri, 2018, p. iv)

World Economic Forum (WEF, 2018) acknowledged the establishment of multipartite partnerships to rethink, create or reform education systems in term of curriculum, pedagogy, structure, and mechanisms that can cultivate talents that adaptable to fast-changing world as revealed below:

> *... relatively few organizations have so far formulated comprehensive workforce strategies for the IR4.0. ... it is our hope that this knowledge can incentivize and enhance partnerships between governments, educators, training providers, workers and employers in order to better manage the transformative workforce impact of the IR4.0.* (WEF, 2018, p.8)

On top of that, it appeared evident that collaboration has become one of the significant avenues in developing twenty-first century skills as well as its integration into educational approaches nowadays (Laal & Ghodsi, 2012; Marjan Laal, Mozhgan Laal & Kermanshahi, 2012; Trisdiono, Siswandari, Suryani & Joyoatmojo, 2019). The philosophy of collaboration entrenched from interaction and personal lifestyle of the learners who take charge of their own learning, as well as showing respect to the abilities and contribution of peers (Marjan Laal *et al.*, 2012). The collaboration could be structured or unstructured, which of each of them could determine how participants in such collaboration structure to interact in variety of manners and subsequently impose different effects on student's learning.

Collaborative learning (CL) is one of the educational approaches that has been adopted in science education, which engages learners in problem-solving, task completion or product creation cooperatively. Various forms of CL had been studied which involves various parties in different settings, such as collaboration among 'students', 'teacher and students', 'scientist and teachers' in inquiry-based instructions (IBE) (Wormstead, Becker & Congalton, 2002; Trautman & Makinster; 2005), curriculum design (Pat Shien & Tsai, 2015), teacher training and education (Choudry, Bianchi, Chippindall & Black, 2017) etc. Recently, several studies have examined the scientist-teacher-students (STS) partnership in project or problem-based learning (Hsu & Roth, 2010; Peker & Dolan, 2012; Burguin, Sadler & Koroly, 2012; Schielke, Schmidt & Scheppler, 2014; Hsu, 2018; Ng & Fergusson, 2019). These studies signpost the significance of youth-scientist coalitions as authentic learning opportunities to impact students' science learning for college and work readiness in future, especially at secondary school level (Schielke, Schmidt & Scheppler, 2014). In other words, welcoming scientist to join the science education as one of the stakeholders is a trending initiative, which formerly and usually only involves science teachers, to foster a group of science literate students with high competency, simultaneously fulfilling the aspiration of 60:40 policy of students' enrollments into science and art streams.

Mutual partnerships, as one of the forms of CL, did exist between scientist, teacher, and students for various meaningful endeavors and fields such as research apprenticeship programme, technology integration, inquiry-based learnings etc. (Wormstead et al., 2002; Adams & Hemingway, 2014; Houseal, Abd-El-Khalick, & Destefano, 2014; Shein & Tsai, 2015, Hsu, 2019). Both scientist and science teacher are more knowledgeable personnel as scientific research practices expert and science educational contents experiment in the fields, respectively. Thus, it is believed that these two professionals could team up to nurture students with scientific literacy during the journey of science knowledge and skills acquisitions. Nonetheless, from the viewpoint of "social interactions promote learning", the complexity and intricacies of social relations or interaction mechanisms, which are highly contextual-based, between scientist, teacher and students needs to be deciphered, detailed and well comprehended to result in meaningful science learning for such tripartite collaboration.

To well comprehend CL, it is crucial to consider, interpret, and adapt to participants' acts, reactions, behaviors, conversation and socioemotion during the collaboration from physical and verbal interaction perspectives. The genesis of interaction of CLs can be viewed from two angles: (1) neutral task area and (2) social emotions, i.e. socioemotional area (Bales, 1950). Both areas of analysis picture the interaction pattern and dig deeper into the interactive strategies deployed among the participants throughout the process of science learning.

1.2 Background of Study

Engaging students with inquiry-based education (IBE), such as project (PjBL) and problem-based learning (PbBL), is two of the contemporary pedagogical activities to sustain the interest of students, as well as promoting more holistic science learning with more experiential and authentic context. These teaching approaches place students' ideas, questions, and observations at the centre of learning experience, which requires them to engage in evidence-based learning and creative problem-solving.

PbBL is a student-centred pedagogy that originated in 1960s. Students work in group to solve the problem about a topic prescribed by teacher. Students are encouraged to provide solutions based on the problem given and there is no one correct and standard answer. The outcome of PbBL may be tangible or a proposed solution, expressed in writing or in a presentation (Khattak, 2018).

PjBL was first termed by the work of John Dewey and William Kilpatrick in 1918 (Larmer, 2014). It requires students to learn by investigating a complex question, problem, or challenge in the form of a project. This approach promotes active engagement of students throughout the learning process and high-order thinking (Savery, 2006). Students solve the real-world, take control over the progress of project, how the project will finish, as well as the outcome of project. It tends to be lengthy for weeks or months to complete the project, which follows more structured and general steps of learning. The outcomes of the PjBL usually involves creation of products, systems, or performances.

In this study, how do PbBL and PjBL merge to "problem-project based learning" (PPbl) in authentic research setting after rigorous literature reviews? In short, in PPbl, the solution to the *problem* proposed was done through a *project* which yield a product, in this case, the results from experimentations to answer the inquiry on the antioxidant capacity of hot spring algae in this study. PPbl provides opportunities to students to have applications of science knowledge and skills learnt in classroom, from studying well-defined *problem* by their own followed by "realisation" of the solution proposed to produce the outcome either a working solutions, invention, innovations, or prototypes through *project* execution that showed high relevance of real-life problem solving which fulfil the call of socio-scientific community (will be detailed in Chapter 2).

1.3 Problem Statement

All students, not just destined for science-related careers, can be benefited from the knowledge and skills provided from science education such as critical thinking, data analytical skills, collaborative skills, as well as oral and written communication skills (Eggert, Ostermeyer, Hasselhorn & Bögeholz , 2013). Students need to learn science in sociocultural context which will contribute to socio-scientific decision making in resolving issues and problems in society rather mere conceptual understanding to increase the science learning relevancy by connecting to the current trends and issues in Science, Technology, Engineering and Mathematics (STEM) worldwide. (Resnick, 1991; Packer & Goicoechea, 2000; Hsu & Roth, 2010; Eggert *et al.,* 2013; Siribunnam, Nuangcharlem, & Jansawang, 2014). Australian Education Council (2018) stated bringing real world content into the classroom is effective in exposing students with worldwide issues that they need to care about.

To support the call, IBE provided an impactful learning experience to students to 'act like a scientist' especially at secondary school level (Scruggs, Mastropieri & Graetz, 2004; Mumba, Banda, & Chabalengula, 2015; LaForce, Noble & Blackwell, 2017). Students engage in problem identification, conduct research, analyze data, and perform science communications through publications in journals, poster presentations etc. to share their findings, thoughts and recommendations to publics or scientific community. Hence, students witness how science and social responsibility are interconnected. This pedagogical activity makes the 'school science' learning to be more 'authentic'. Assuredly, students seek to answer the questions about "How am I going to use all the science knowledge learnt in classroom in real world context to extend my understanding and contribute to knowledge?" after completing the PjBL or PbBL tasks.

Unfortunately, nowadays, declines in students' enrolment in STEM-related fields at secondary and tertiary education level are trending (Alan, Zengin & Kececi, 2019; Ergün, 2019; Halim & Meerah, 2016; Jaremus, Gore, Fray & Prieto-Rodriguez, 2019). Ministry of Education (MoE) (2018) reported the slump of students' enrolment in science stream by approximately 9,000 students from 2017 to 2018 (92,956 to 83,608 students for Form Four Science; 93,345 to 83,786 students for Form Five Science Students), which was approximately 10 times less than in art stream (MoE, 2018). Notwithstanding that, many students decided to pursue non-STEM related fields after completing secondary and post-secondary level of science stream courses (Zhou, Zeng, Xu, Chen, & Xiao, 2019; Chin, 2019). According to Carnevale, Smith and Melton (2011), only half of those students completed the STEM degrees who originally studied STEM majors during secondary level. These scenarios were alarming and led to concern among policymakers about their country's STEM workforce and scientific literacy of their populations (Van Griethuijsen *et al.,* 2015). In the case of Malaysia, the continuous shrink of students' enrolments in science stream till failure to meet the demand of 60% of annual national cohort (approximately 270,000 students) would result in the shortage of human capital in STEM related fields which would hamper the socioeconomic development of the country in couple of years (Academy of Science, 2017). This phenomenon could be attributed to issues that might be related to the existing science educational pedagogies that might transfer the science knowledge at surface learning level (such as didactic teaching that asserting remembering and understanding facts) and yet to reveal the invisible spectrum of science learning (such as relevancy, application, and synthesis of science knowledge) (Childs, Hayes, & Dwyer*,* 2015).

Unquestionably, science learning should reveal high relevancy to boost students' motivation, attitudes, and interest. It should show interconnection between what students learnt in classroom and daily life phenomenon, real-world issues, and problems. However, this integral part of science in real-world context and human's daily living is not manifested in school science teaching (Childs et al*.,* 2015). Substantial number of studies posited that one of the factors making science education remains unpopular among many students was the irrelevant of science in daily life (Dillon, 2009; Gilbert, 2006; Hofstein, Eilks, & Bybee, 2011; Holbrook, 2008; Osborne & Dillon, 2008). Students often perceive science as difficult subject to learn, afraid of making mistakes and failures, or even lack willingness to put efforts in equipping themselves with knowledge and skills to attain a STEM-related jobs (Fadzil, Saat, Awang & Hasan Adli, 2019). For all those due to the view and perception of school that the learning of science should focus on delivering basic science concepts with the goals of preparing students for understanding science concepts to sit "paper and pencil tests" rather than educating them science (De Jong & Talanquer, 2015; Chin, 2019).

Learning science usually involves laboratory works or practical lessons, which are considered as the essence and nature of scientific expertise. Students should be able to do experiments in the quest of scientific knowledge acquired in the classroom. Otherwise, our science lessons are no more focusing on hands on scientific investigation (Ng, 2014). This might be due to lack of resources (Abrahams, Reiss, & Sharpe, 2013; Fuccia, Witteck, Markic, and Eilks, 2012; Ng, 2014; Fadzil & Saat, 2017). Exacerbating the problem is students have no interests in pursuing STEM-related subjects might be due to how science subjects are taught. Many science lessons do not take science experiments into accounts and science teachers are not competent enough to teach science, especially IBE and scientific investigation (Alan, Zengin, & Kececi, 2019; Fadzil & Saat, 2013). Most of them adopted "cookbook" style in teaching science subjects (Abrahams et al., 2013; Schwichow, Zimmerman, Croker, and Härtig, 2016). Rudolph (2019) argued that it might be inappropriate to teach scientific method in current or existing science curriculum. The five-step methods (observing and asking questions, forming a hypothesis, making a prediction by gathering evidence, testing the speculation, and arriving at a conclusion) as proposed becomes problematic as argued by scientists because this pedagogy is inaccurate and leads to the reductive to the idea of science (Rudolph, 2019) such as no involvement of students in developing research questions (Chinn & Malhotra, 2002) and cook-book style of science inquiry learning, i.e. students were given set of procedures and conduct the experiments rather than negotiating experiment design and procedures (Hofstein & Lunetta, 2004). Such activities are often "hands-on", but students are not frequently "minds-on" to epistemically involve in experiment and laboratory activities design (Burgin, Sadler & Koroly, 2012). This pedagogy does not show how science works and teacher, who had no experience in doing scientific research, would revert the science process to teaching almost by rote (Alan et al., 2019; Fadzil & Saat, 2013;

Rudolph, 2019). All these addresses a need to innovate alternative science pedagogy which give emphasis on how science works than the contents of scientific disciplines.

In addition, according to Australian Education Council (2018), the incongruency exists between declining students' STEM learning outcomes and engagements and increasing needs of highly capable STEM graduates due to technological advancement and automation nowadays. This indicated that students often do not aspire STEM career because they struggle to see the relationship between STEM disciplines and the careers they aspire (Australian Education Council, 2018). Students did not truly see how science is used by researchers to study a phenomenon, solve problems as well as improve the existing solutions through laboratory or practical works. Socio-scientific decision making could not be aligned with current practices of PjBL and PbBL without scientific expertise involvements (Resnick, 1991; Packer & Goicoechea, 2000; Hsu & Roth, 2010; Eggert *et al.,* 2013; Siribunnam, Nuangcharlem, & Jansawang, 2014). The science learning nowadays becomes bound to formal setting and less influential on students' experiences and thinking beyond the confines of school (Cobb, 1994; Serdykuvoz, 2017).

Therefore, students need to be exposed on how scientists apply science knowledge in workplace and research which are termed 'authentic' science (Houseal, Abd-El-Khalick, & Destefano, 2014; Ufnar & Shepherd, 2018). Furthermore, it is prominent to provide students with the ability to conduct authentic research to introduce the notions of problem solving (Hsu & Roth, 2010; Peker & Dolan, 2012; Burgin et al., 2012; Schielke et al., 2014; Hsu, 2019). The perception of students of STEM and skills in real life context will allow them to construct linkage between their science knowledge, science in society and scientific careers (Salonen, Hartikainen-Ahia, Hense, Scheersoi and Keinonen, 2017). Thus, collaboration or partnership between scientific community and science educators becomes promising to address this issue (Adams & Hemingway, 2014; Houseal et al., 2014; Shein & Tsai, 2015), or termed "scientist-teacher-students collaboration" (STSC) in this study. Scientist is the professional individual who is trained to make meaning of scientific information. Schielke et al. (2014) asserted the role of scientist in providing students with ability to conduct authentic research is becoming more significant nowadays, especially at high school level.

While such collaboration apparently brings benefits to teachers, students, and scientist, yet there are some constraints that need to be pondered. While teacher and students (schools) and scientist (industry) are keen to form partnerships, each of them has differing objectives and cultures. Scientist found school world is foreign to them and teacher are also not familiar with scientists' scientific cultures (Peker & Dolan, 2012; Tanner et al., 2003). It is certainly challenging to establish and maintain mutual partnerships that works for both parties (Australian Education Council, 2018, Houseal et al., 2014). Thus, numbers of partnership designs have been adopted such as scientist-teacher mentorships, workshops, science camps and awards programme (Falloon, 2013; Evans, Abrams, Rocks & Spencer, 2001).

Previous studies revealed the positive attitude, conceptions, and growing motivation by students in learning science due to the exposure to scientist-teacher partnership programme (Claudio, 2001; Shein & Tsai, 2015; Ufnar & Shepherd, 2018). Thus, this endeavor should not be undervalued in reforming science education. While this mutual cross-institutional partnership appears to be ideal for science and STEM education in our country, yet there are finite mechanisms to support and implement this collaboration. Most of the past studies examining the involvement of scientists focused on the gains in students' achievements (Laursen, Liston, Thiry, & Graf, 2007) or interest in science (Sadler, Burgin, McKinney, and Ponjuan, 2010). However, there is a need to illustrate the how both scientist and teacher interacts with students through authentic investigation for helping students to increase engagement and helping students to learn science in the notion of problem solving (Peker & Dolan, 2012). In addition, there has been ample of research investigating the ways of teacher to help students make meaning in science learning (teacher-students partnership) (Mortimer & Scott, 2003) and scientist-teacher collaboration, however the understanding of the interactions among parties in STSC as well as their interactions in influencing students' science learning process through PPbl in authentic research setting has not been a focus of study (Adams & Hemingway, 2014; Houseal et al., 2014; Peker & Dolan, 2012; Sadler et al., 2010; Tanner et al., 2003). Extensive knowledge of how this partnership work is important, especially in term of working implementation from perspective of science learning and social interaction. Students are the ultimate beneficiaries of the skills and knowledge transferred by both scientist and teacher in this study. Thus, the social relationship and interaction between scientist, teacher and students in this context needs to be explored in-depth to assure effective transmission of science knowledge to students.

1.4 Aim of the Study

The aim of this study is to shed light on the interactions between scientist, teacher, and students through interaction process analysis (IPA) and structural exchange pattern (SEP) situated in authentic research setting.

1.5 Research Objectives

The objectives of this study are to

1. To investigate the interactions between scientist, teacher and students in problem-project based learning in authentic research setting.
2. To investigate the structural exchange pattern of identified interaction process between scientist, teacher and students in problem-project based learning in authentic research setting.

1.6 Research Questions

To study the two objectives stated, two research questions are constructed as follow:

1. What are the interactions between scientist, teacher and students in problem-project based learning in authentic research setting?
2. What is the structural exchange pattern of identified interaction process between scientist, teacher and students in problem-project based learning in authentic research setting?

1.7 Scope of the Study

This study focused on a scientist from a research institute, a science teacher (researcher himself) and four selected students who pursued science stream courses from an independent high school in Kuala Lumpur, Malaysia. The outcome of this study generalized only this case of scientist-teacher-students collaboration (STSC) rather than the entire population in Malaysia. This is considered an exploratory study to understand how interaction process of collaboration takes place in PPbl in authentic research setting.

1.8 Limitations of Study

Every research has its own limitations. The researcher himself conducted the research with his students as participant observer. This is because researcher would like to understand the interaction between scientist, teacher, and students. The researcher immersed himself into the interactions and record the entire observation field notes (descriptive and reflective) during and after the session. This caused the researcher failed to videotape or audiotape the interaction process between scientist, teacher and students in problem-project based learning (PPbl). Also, the presumption of researcher would result in the bias in interpretation of observation field notes. To overcome this limitation, the findings of each data collection method are triangulated with reflective journals provided by students and member checked by scientist and students.

The STSC was fostered upon the consensus between school and research institute pertaining to the nature of task (research topic), the complexity of task as well as duration of collaboration. The selection of project's topic for collaboration in this study was made based the available expertise offered by the research institute. The scope of the scientific research topic for collaboration was determined upon discussion between scientist and teacher based on the problem identified and intended to be solved by students. The duration of collaboration was allocated based on the school academic calendar as prescribed by MoE.

Also, the personal attributes (membership characteristics) of scientist, teacher, and students in interaction of PPbl in authentic research setting were not studied before the collaboration takes place. Researcher presumed that the willingness of scientist and students to take part in this collaboration would contribute to the success of collaboration in this study through purposive sampling (will be discussed in Chapter

3). The students selected by the researcher were interviewed to assure they possess positive characteristics of scientific knowledge and attitudes prior to this collaboration.

The process of collecting data using participant observation was not easy. It was not realistically possible to attend every social interaction especially during the scheduled or spontaneous division of labors between students in doing practical works and experiments at different times and places simultaneously. To possibly obtain the complete description of interactions between participants, researcher needed to infuse reflective journaling technique to the students in this study to validate the participant observation notes or looking for the missing part that might not be recorded in participant observation notes.

The study on interaction between scientist, teacher and students in collaboration was not an easy process due to its complexity (Gnisci, Bakeman and Quera, 2008). In this study, researcher paid more focus on party-to-party linkages rather to person-to-person linkages in studying scientist-teacher-students interaction. This is because researcher would like to get a whole picture of how these three parties (scientist, teacher, and students) interact which can affect the science learning of students.

1.9 Significance of Study

This study is significant because it is a preliminary research that incorporates macro and micro level interaction analysis. of STSC-PPbl. At school level, the findings of this study could serve as the evidence base to formulate more effective implementation of collaboration between research institutes or universities and schools, as well as industry-school partnerships (Australian Education Council, 2018). According to Australian Education Council (2018), it is evident that industry is well place to work with governments to better understand the workforce needed in future. Partnership between school (teacher and students) and industry (scientist or researchers) improve career awareness and understanding of the opportunities afforded by STEM skills and knowledge, teacher professional learning by increasing discipline specific knowledge and linkages to real world practice, as well as increases outcomes and impacts of science education and learning *via* the use of data and evidence. By understanding how scientist, teacher and students interacted with each other, the stakeholders could propose the interactive strategies at implementation level to make this collaboration meaningful and success for authentic science learning.

This exploratory study also revealed the involvement of scientist and teacher in guiding students to complete an authentic scientific investigation. Even though there were many conditions (such as group heterogeneity, topic of study, genders of participants etc.) could contribute to the less wholesome and inductive description of STSC interaction during problem-project based learning in this study, this baseline study could serve as the reference material for educational bodies or institutions such as MoE to promote more in-depth and ongoing educational research activities on such collaboration for policymaking in future.

1.10 Definition of Terms

Interaction, or social relations, refers to reciprocal actions or influence among a group of individuals (Weber, 1978). Social interactions are ubiquitous and intricate in daily life. In this study, it refers to the reciprocal actions or influence between scientist, teacher and students in various forms of physical or verbal interactions such as conversation, behaviour, emotions, reflection or scaffolding through explicit identification of collections of actions, behaviours, reactions, bevhavioural responses, feelings, facial expressions etc. that allowed them to work together in studying antioxidant capacity of hot spring algae in PPbl in authentic setting as recorded in participant observation notes by researcher and validated by participants (students and scientist) through member check.

Neutral Tasks is the small essential piece of a job that serves as to differentiate various components of a project with little or no involvement of individual's emotions and relationship to society. There are three subareas namely orientation, evaluation, control (Bales, 1950) and one emerged theme named independency. In this study, it refers to the collection of actions, reactions or behaviors which reported as functions manifested by scientist, teacher, or students with the view of little or no involvement of individual's emotions and relationship to each other during the interaction in PPbl as recorded in participant observation notes and validated by participants through member check in this study.

Problem-Project Based Learning (PPbl) in authentic research setting refers to the students-centred pedagogy that comprises of authentic learning, scientific investigation, problem-based learning, and project-based learning. In other words, this pedagogical activity combines both features of problem and project-based learning as conceptualized in the literatures ((Barron and Darling-Hammond, 2008; Ertmer and Simons, 2005; Mergendoller and Thomas, 2005; Hung, 2008, Tse and Chan, 2003). It requires students acquire a deeper knowledge through active exploration of real-world challenges and problems. In this study, PPbl refers to the investigation of antioxidant capacity of hot spring algae by learning community comprises of scientist teacher and students. Students need to first identify the topic of interest that they need to be studied that serves as the "problem" (in this study, the potential use of hot spring algae) and propose the solutions (in this study, the antioxidant capacity of hot spring algae) that is feasible to be investigated, which as prescribed in one of the characteristics of PbBL. The problem must be an issue of interest to be solved in real-world, within the context of authentic tasks and settings prior to discuss with scientist and teachers. Then, students need to carry out the PjBL on the problem posed with scientist and teachers for prescribed weeks or months. In sum, it refers to the long-term problem identification, scientific investigation, and communication of findings on the antioxidant capacity of hot spring algae to acquire scientific knowledge and skills in a research institute in four activities as prescribed in this study.

Scientist-Teacher-Students collaboration (STSC) , as conceptualized from the literature (Wormstead et al., 2002), refers to a tripartite collaboration (collaboration involves three types of parties) and interaction between Form Five students, an upper secondary science teacher and a scientist from a research institute in a research laboratory which involved a mutual learning *via* partnership through PPbl in a research laboratory in this study.

Socioemotional area, or social emotional-related area, is the small essential piece of a job that serves to differentiate various components of a project with involvement of individual's emotions and relationship to society. There are three subareas of socioemotional tasks: decision, tension management and integration (Bales, 1950). In this study, the individuals refer to scientist, teacher and students and the society refers to small group of scientist-teacher-students. It refers to the collections of actions, reactions, behavioral responses (b.r.), facial expression (f.e.) or feeling (f.) manifested by scientist, teacher, or students with involvement of individual's emotions and relationship to each other during the interaction in STSC-PPbl as recorded in participant observation notes and reflective journals from students, validated by participants through member check in this study. in this study.

Structural exchange pattern (SEP) refers to structural element of interaction including Intensity of Interaction Functions, (Neutral Task Areas or Socioemotional Areas), Density of Interaction, Intensity of Modes of Collaboration), Active to Passive Neutral Task Ratio, Positive to Negative Socioemotional Task Ratio and Independent Task Ratio as conceptualized from the Fahy (2001)'s study. In this study, it pictures the structural pattern of STSC in studying antioxidant capacity of hot spring algae in PPbl in authentic setting by quantifying the qualitative codes, meaning units, condensed meaning units through derived from three-stage analysis of participant observation notes of four activities through labelling of neutral task area (active and passive) and socioemotional area (positive and negative) adapted from Bales (1950) and Fahy (2001) as prescribed in this study. It is the percentages calculated from the quantification of qualitative codes and labels using the Equation 3.1-3.7 from interaction process analysis of participants observation notes in this study.

1.11 Summary

This chapter entailed the needs of fostering industry-school partnership *via* the form of STSC-PPbl as well as the study on the interaction process in problem statement, background of study and significance of study. Two main research objectives and questions were put forward to investigate the interaction process of STSC-PPbl. The scope and limitations of the study were acknowledged.

CHAPTER 2: LITERATURE REVIEWS

2.1 Introduction

This study explored the interactions between scientist, teacher and students and structural exchange pattern of interaction in problem-project based learning (STSC-PPbl) in authentic research setting. This chapter discusses the definition of collaboration, research paradigms of collaboration, level of structure of collaboration, partnerships in science education, inquiry-based learning, and Balesian interaction process analysis. The theoretical framework was built to serve as guide in this study.

2.2 Definition of Collaboration

This section discusses the definitions of collaboration from three perspectives: theoretical, qualities of collaborative learning (CL) and historical perspective as discussed and argued by various researchers prior to explore the interactions of STSC in this study.

2.2.1 Theoretical Perspective

Dillenbourg, Baker, Blaye, and O'Malley (1996) have had attempted to define collaboration as *"collaborative learning"*(CL). Collaboration is first broadly defined as a condition or circumstance which two or more people learn or try to learn something (knowledge, skills, values etc.) together especially in joint problem solving (Dillenbourg, 1999). Roschelle and Teasley defined the collaboration as the "mutual engagement of participants in a coordinated effort to solve a problem together" (as cited in Dillenbourg *et al.,* 1996). Dillenbourg (1999) defines 'learning' as

- the course or materials in order to sit an examination by students;
- a by-product of collaboration or interaction due to joint problem solving;
- a biological or cultural process that takes place over prescribed periods or several years;

- a lifelong acquisition of expertise within a professional community.

Roschelle (1992) posited collaboration as a practice to reach convergence in thinking throughout the interactions. Participants in the collaboration process shall construct shared meaning throughout the construction, repair and monitor of knowledge. Convergence takes place gradually but tends to include four elements: a) construction of an abstract understanding of the problem's deep structure; b) the interplay of metaphors; c) an iterative cycle of displaying, confirming, and repairing conceptions; and d) application of progressively higher standard of evidence for convergence. The collaboration should take place in a joint problem space to allow the meaningful conversations about the problem. van Boxtel, van der Linden, and Kanselaar (2000) stated that CL enables students to provide explanations on their understanding at cognitive level, which assist students to delineate and reorganize their knowledge structure. Social interaction would help students to achieve the goals of knowledge restructuring as teammates, peers or group mates would work in coordinate to improve their comprehension of concepts.

2.2.2 Qualities of Collaborative Learning

Dillenbourg *et al.* (1996) posited although there might be some division of labours during collaboration, the cognitive tasks or processes in problem solving would be divided in the way of all of them are interconnected to each other, and coordination is key to assure the collaboration process goes smooth.

Degree of interactivity and negotiability also characterize the collaboration process (Dillenbourg, 1999). Interactivity is the extent which the interaction influence participants' thinking or cognitive processes, meanwhile negotiability refers to the extent of which group members work toward common understanding. It means that no a single individual can impose his or her understanding unilaterally to all others.

2.2.3 Historical Perspective

Much of the research on CL is rooted in the work of Piaget and Vygotsky (Dillenbourg, 1996). The CL is first discussed based on socio-constructivist approach. This approach borrowed Piagetian Theory of Development to describe the cognitive process of children, as well as the ideas of cognitive conflict. Piaget asserted cognitive conflict is essential for learning and growth. Social interactions, in this case, interaction among peers experienced by students could facilitate the cognitive conflict to allow more advanced developmental growth. This is because everyone possesses different knowledge, different knowledge representation schemes and different reasoning mechanisms (Dillenbourg, 1996).

Instead of emphasis on cognitive conflict, Vygotsky posited the importance of social interactions to cause cognitive growth or change within the learners. Learners internalises the social interaction and result in the conceptual change in the learners to construct new knowledge (Dillenbourg, 1996). The social interaction between novice and expert will result in the development of more sophisticated skills or knowledge of the novice learners (Dillenbourg, 1996).

Situated cognition theory (Brown, Collins and Duguid, 1989) viewed environment as an integral part of collaboration. They perceived that social structures need to be taken into consideration in studying collaboration. Thus, knowledge is co-constructed through social interactions among collaborators. Group interactions are not necessarily predictable based on the input of group members. Thus, observing group interaction as a unit of analysis rather than individual group members will produce different qualitatively different observations about collaboration (Dillenbourg *et al.*, 1996).

2.3 Paradigms of Collaboration

The research on collaboration can be categorized into three paradigms: “effect”, “condition” and “interaction” as discussed below.

2.3.1 The “effect” paradigm

Research on the collaboration in the “effect” paradigm tends to study the outcome of collaboration, comparing group performance with individual performance. Past studies showed that collaboration impose sound effects on student learning and performance (Tudge, 1992; Webb, 1993; Saner, McCaffrey, Stecher, Klein, & Bell, 1994; Fall, Webb,& Chudowsky, 1997). Behaviour during group collaboration was significantly related to individual’s ability. Students who received help during collaboration and who attempted to understand the assistance they received perform academically than students who passively received assistance (Webb, 1993). However, there is an argument on the effect of collaborative learning on different ability of students. Most of the lower-ability students were benefited from the collaborative learning, while it has no or declined effects on academic performance of the higher-ability students (Tudge, 1992; Webb, 1993; Saner *et al.*, 1994; Fall *et al.,* 1997). Therefore, there is a possibility that less sophisticated student could persuade the student who are more sophisticated in learning, especially when they are lacking confidence with the absence of confirming or disconfirming evidence.

2.3.2 The “condition” paradigm

Research on the collaboration in the “effect” paradigm tends to determine the conditions moderating the effectiveness of collaboration on learning, for instance, personal characteristics of group individuals, group heterogeneity and size and task features (Dillenbourg *et al.,* 1996; Johnson, Johnson, Stanne, and Garibaldi, 1990; Johnson, Johnson, Ortiz, and Stanne, 1991; Webb, 1984a, 1984b, 1989, 1991).

Task characteristics may affect the collaboration on group learning. The quality of group conversation is affected by the extent of task which requires the group members to communicate and collaborate with each other (Mercer, 1996). The tasks designed shall encourage the practice of planning, decision-making and interpreting feedback. Group members should interact and talk with each other to complete the tasks, as well as staying cooperative rather than competitive. Webb (1991) believed that giving group rewards is more likely to promote helping behaviors in collaboration.

2.3.3 The "interaction" paradigm

The "interaction" paradigm attempts to identify mediating mechanisms between collaboration and learning outcomes (Dillenbourg *et al.*, 1996). Research on collaboration in term of "interaction" paradigm describes characteristics and processes of interactions through collaboration. For instance, Dillenbourg *et al.* (1996) suggested that the extent to which social interaction produce elaborated collaboration is considered one of the mediators of the effect of the collaboration. Mercer (1996) stated that the interaction with elaborated explanations allows students to learn the principles underlying practical procedures and strategies, making the learning are more generalisable and transferrable to new situations.

Webb (1991) posited that quality of the interactions does affect the collaborative learning. He noted several factors that contribute to the success of providing and receiving elaborated explanation to improve students' learning through collaboration: (1) whether the students receiving the explanation actually needs assistance; (2) whether the students has the chance to practice the new skills independently; (3) the relevance and timeliness of the information provided; (4) the understanding on the assistance provided and lastly (5) whether the student take advantage of those opportunities. Besides that, the learner who is assisted may lack the motivation to try to solve the problem individually (Webb, 1991).

In this study, researcher explored the STSC-PPbl using interaction paradigm from situated cognitive perspective. This paradigm aided researcher to explore how scientist, teacher, and students 'shape' the collaboration and are shaped by collaboration through process and characteristics of interactions in the context of authentic research. This also helped researcher to picture the interaction pattern among the participants and dig deeper into the interactive strategies deployed throughout the process of learning.

2.4 Level of Structure of Collaboration

There are two levels of structure of collaboration: unstructured and structured collaboration. Unstructured collaboration is the level of structure of collaboration in which there can be guidelines in a collaboration session, however it remains flexible and no strict rules (Borresen, 1990; Dees, 1991; Keeler & Steinhorst, 1994; Reglin, 1990). Participants are left to their own devices to come up with ideas, which is agile and flexible. Besides that, participants are free to spew any idea that comes to mind. The examples of unstructured collaboration are general brainstorming session and online collaboration projects.

Structured collaboration rules are put in place to help guide the discussions and outcomes. The rules will vary between organisation and project but can include anything that will help. Some organisations have strict classification rules or restrictions on the types of groups and events that can exist in the organisation (Heller, Keith & Anderson, 1992; Norwood, 1995; Smith, Hinckley & Volk, 1991).

The relationship among the level of structure imposed on the collaborative exchange, task complexity and achievements outcomes were not well comprehended

(Yetter, *et al.*, 2006). However, on the contrary, it is likely to interfere the achievements of participants who are working on higher level skills such as complex problem solving when structured collaboration was applied (Cohen, 1994). It is noteworthy, however, that studies have shown benefits for the acquisition of higher order thinking skills for both structured (Heller et al., 1992; Norwood, 1995; Smith et al., 1991) and unstructured forms of collaboration (Borresen, 1990; Dees, 1991; Keeler and Steinhorst, 1994; Reglin, 1990).

In this study, researcher adopted unstructured collaboration in formulating STSC-PPbl in authentic research setting. This kind of collaboration is more 'naturalistic' which suited the purpose of this study to explore the "natural" scientist-teacher-students (STS) interaction between during the process of collaboration.

2.5 Scientist-Teacher-Students Collaboration (STSC) in Science Learning

Fostering collaboration between scientific community (scientist) and science educator (teacher) has become one of the increasingly popular approaches to bridge the gap between industry or tertiary educational institution and school in reforming existing science education (Adams & Hemingway, 2014; Houseal et al., 2014; Shein & Tsai, 2015). According to past studies, such tripartite partnership and collaboration benefit various parties in term of science education

STSC provided teacher fresh perspective of scientific inquiry process, extend their pedagogical content knowledge and renew or innovate their teaching in the classroom (Houseal et al., 2014; Schielke et al., 2014; Tanner et al., 2003; Ufnar & Shepherd, 2018). Teachers could take the opportunity to facilitate the science learning between scientist and students using variety of learning strategies to engage diverse learners with different learning styles and interests. Besides that, scientist can help teacher to grow professionally in their own subject matters and fields. Teachers will keep updated with the contemporary progress and development of science and technology worldwide, thus they can educate students with latest knowledge without being "off-tracked" (Schielke et al., 2014).

Schielke et al. (2014) asserted the role of scientist in providing students with ability to conduct authentic research is becoming more significant nowadays, especially at high school level (Evans, Abrams, Rock & Spencer, 2001; Peker & Dolan, 2012; Schielke et al., 2014). Scientists mentor and advise students to complete a research investigation. This experience is highly valued by the students, as well as the university or research institute they matriculate to. Some of these students will co-author publications and presentations with their advisors, absolutely providing them with real-world research experience and contribution to new knowledge.

Scientist can bring new and current topics into classroom. Scientist can provide expertise within the context of an authentic problem or pertaining to regular science classroom curriculum (Schielke et al., 2014; Peker & Dolan, 2012; Mullis & Jenkins, 1988). This will help students to see the association between what they learnt in science classroom and what is happening in the real world. Scientist models the transmission of knowledge that it is permissible not to know everything, and students will soon realize that there is no stupid or bad question to ask. This allow students to practice lifelong learning, future decision makers and leaders of our global community.

Scientist can take this chance to enhance their communication skills and pedagogical skills during the interaction with students from school (Tanner et al., 2003). Schielke et al. (2014) suggested students to submit their questions to scientist in advance. By doing this student can clarify their questions, and the scientist can be prepared to meet their needs. In addition, students can address their own questions and interests to scientists upon their learning experience. Simultaneously, students can develop skills such as note taking, interviewing and interactive discussion.

Next, scientist can demonstrate and emphasise workplace skills, which include both ‘hard’ and ‘soft’ skills, to students in the classroom (Schielke et al.,2014). This can also help reinforce important life and job skills, such as appropriate communication skills, proper dress codes and attire, punctuality, and general responsibility. This will indeed motivate students as they felt that what they do at school really matters to someone in the real world.

Students become energized and excited to explore new areas and potential career pathways. Students begin building a network with professionals and surrounding community. In affective domain of learning, students gain greater awareness and appreciation of scientific and professional community, regarding their contributions to the socio-economic development (Schielke et al., 2014). It enriches students’ learning experiences by providing access to scientific community and content knowledge, which in turns improve their science performance and learning (Houseal et al., 2014; Tanner, et al., 2003). Furthermore, students could gain self-confidence in their abilities to interact with professionals (in this case, scientists) (Schielke et al., 2014). It could be challenging for students to interact and approach experts in the classroom. However, it is always beneficial for students when scientists are willing to pay attention to them, carefully and thoughtfully listen and respond to their questions aroused.

2.6 Multipartite Partnerships between Scientist, Teacher and/or Students in Science Education

STSC is the relationship in which the students, with the support of teachers, participate in and contribute to the research of scientists, which contribute to the authentic context of learning (Wormstead et al., 2002). Authentic learning is the learning process aims to connect what students learnt in classroom or school to real-world issues, problems, and applications (Strobel, Wang & Weber, 2013). According to National Research Council (2000), authentic science learning refers to involve student to "learn science like a scientist" or "learn science to be a scientist", resembling the science and engineering practices such as asking scientific questions, designing, and conducting research, generating and testing hypothesis, and communicating results *via* science communication and reporting. This type of learning process is also characterized by students' ownership of research problem and their epistemic authority in determining how the research problem to be addressed (such as designing the research, selecting variables, choosing methods for data collection, analysis and interpretation), as well as the complexity of their reasoning as they interpret the results (Chinn & Malhotra, 2002). The section reviewed some past studies related to various designs of partnerships, including scientist-students, scientist-teacher, scientist-teacher-students, and scientist-teacher-industry, in science education, ranging from primary to secondary school level or both.

Burguin et al. (2012) stated the students' experiences and learning outcomes associated with participation in scientist-students collaboration in research apprenticeships were most likely to be related with desired student outcomes such as science content knowledge, understanding of nature of science, and aspirations for science-oriented career plans. The findings indicated greatest variance in the categories of collaboration, epistemic involvement, and understandings of the significance of research results. The greatest variation in the desired student outcomes was observed in student understandings of nature of science and in students' future science plans.

Scientist-teacher partnership in science education produced deliverables such as teacher's professional development in implementing inquiry-based education (IBE) (Trautmann & MaKinster ,2005), curriculum reform in environmental education (Pat Shien & Tsai, 2015) and science communication programme (Patel, DeManie, Heafield, Banchi & Prokop, 2017). These studies reflected scientist's role as introducing new science contents and teaching strategies into secondary classrooms, as well as scaffolding and receiving feedback from teachers for pedagogical implementation (Trautmann & MaKinster, 2005). The impacts of these partnership include scientists had better understanding on knowledge of students, curriculum, and pedagogical content knowledge, meanwhile teacher showed improvement in content and pedagogical content knowledge (Pat Shien & Tsai, 2015). However, this partnership imposed moderate effect on students' scientific competency (Pat Shien & Tsai, 2015) but remarkable effects in students' interests (individual and situational) and motivation (Pat Shien & Tsai, 2015; Trautmann & MaKinster, 2005). These were in tandem with findings from Masson, Klop and Osseweijer (2016) who claimed the authentic science learning with scientist elevated student's interest in STEM.

Ng & Fergusson (2019) examined scientist-teacher-industry partnership in engaging students with IBE. The findings from mixed method study found that this partnership enhance teachers' teaching and students' learning. However, there was still a need for scaffolding for many of the students. The effectiveness of this partnership depends on the teachers' ability to internalize the new technological and content knowledge and integrate them into existing teaching methods

Finally, STS partnerships include mainly authentic science internship (Hsu & Roth, 2010; Peker & Dolan, 2012) and project-based learning (Wormstead, Becker & Congalton, 2002; Rahm, 2016). In authentic science internship, students learned different dimensions of science and reflect their relationship with science with five categories of experiential descriptions: authenticity of science, channelling and connecting different communities, advance knowledge required in and lengthy procedures mobilised by science and comprehensive science learning (Hsu & Roth, 2010). However, how participants experience a science internship in an "authentic" science setting remained unclear. Peker and Dolan (2012) stated the division of labour among scientist and teacher during the partnership. Scientists provided conceptual and epistemological support pertaining to their scientific enterprise, such as explaining scientific phenomena or aspects of the nature of science, while teacher played an essential role in ensuring students' success to this knowledge. However, extensive training is needed for students to collect and report data accurately to scientists, and preparatory curricula is needed. (Wormstead et al., 2002).

Based on the past studies, it is apparent that the interaction between students, teacher and scientist is not automatically a success factor. Disappointment during scientist-students interaction can weaken the beneficial effect of this collaboration. Hsu (2018) addressed the challenges hinders the partnership between scientist and student includes complexity of science language and communication barrier. Suitable pedagogical tool and moderation need to be introduced to improve scientist-students partnership.

Researcher found that not much study really focused on the detailed description and exploration on interaction between scientist, teacher, and students in the context. Some issues were addressed by past studies that the nature of interaction in such partnership need to be explored. Researcher argued that *how* scientist and teacher interact with students in a context could affect the transmission of science knowledge and learning to students as end receivers. Thus, researcher explored the interaction by using Balesian Interaction Process Analysis (Bales, 1950) to explore the partnership between scientist, teacher, and students in the context of this study.

2.7 Inquiry-based learning

Inquiry-based learning engages students in creation, interrogation, and revision of knowledge, and while developing twenty-first century skills such as critical thinking, collaboration, communication, reasoning, synthesis, and resilience (Barron & Darling-Hammond, 2008). There are two frameworks of inquiry-based learning that will be delineated here: project-based learning (PjBL) and problem-based learning (PbBL). Then, based on the discussion of these two frameworks, this section will also discuss how the concept of PPbl emerged in this study.

2.7.1 Project-Based Learning (PjBL)

PjBL is one of the pedagogical approaches that allows students to learn by experiencing and solving real-world problems. PjBL essentially involves the components below (Barron & Darling-Hammond, 2008):

(a) Students tackle the real-world problems that need to be solved based on their knowledge learnt in classroom

(b) Student-centred learning, i.e. students take over control of their learning

(c) Teacher as coach or facilitator to encourage the process of enquiry and reflection

(d) Students are usually working in pairs or groups

PjBL provides an effective model for whole-school reform in education (National Clearinghouse for Comprehensive School Reform, 2004; Newmann & Wehlage, 1995). Condliffe, Visher, Bangser, Drohojowska and Saco (2016) stated that project design principles most used in PjBL align well with the goals of preparing students for deeper learning, higher cognitive skills, and intra- and interpersonal skills.

While PjBL is criticised is not rigorous enough in past studies, there are some features and components as success criteria of PjBL (Barron & Darling-Hammond, 2008; Ertmer & Simons, 2005; Mergendoller & Thomas, 2005; Hung, 2008) as follow:

(a) The title of project needs to be a realistic problem or project. It must align with students' skills or interest. The scope of the project requires learning clearly defined content and skills such as using rubrics or exemplar from scientists or professionals.

(b) It must be structured group work. The group members of three or four with diverse skills and interdependent roles. Do tell students the team rewards for each goal achieved. Individual accountability should be given based on the growth and performance of students.

(c) The assessment of PjBL needs to be multifaceted. There must be vast number of chances for students to receive feedback and revise their works through some reflective activities. Each criterion of assessment should comprise multiple learning outcomes such as collaboration, communication, problem-solving etc. There must be a platform for students to present their works. The presentation encourages students to participate and signal social values such as exhibition, performances, portfolio, and reports writing.

(d) Students are encouraged to take part in professional learning network. They can collaborate and reflect upon their project-based learning and share with their colleagues in classroom. They can also join some courses related to IBE.

2.7.2 Problem-Based Learning (PbBL)

PbBL is a one of the non-traditional pedagogical techniques which elicit the role of problems in driving the learning process (Tse & Chan, 2003). Firstly, students are presented with a problem, then they need to seek information required to help them to solve the problem (Salas, Segundo, Álvarez, Arellano & Pérez, 2014). This learning approach is considered "student-centered" approach (Tse & Chan, 2003), and the role of instructor is to coach the students to acquire the knowledge and become self-directed learners", instead of lecturing students as in traditional style of engineering and science education (Forcael *et al.,*2015).

PbBL promotes a better comprehension of course concepts and improve students' problem-solving skills as well as their communication, presentation, and collaborative skills. Past studies showed that students find problem-based learning to be a very motivating and effective means for learning (McLoone, Lawlor & Meehan, 2016; Forcael et al., 2015). Students has more engagement in class because they are aware of the acquisition of knowledge and skills which will assist them to succeed in their career developments in future (Stanford University Center for Teaching and Learning, 2001). Recently, educator combined both problem-based learning and traditional teaching in engineering and science education to strengthen the teaching and learning process (Salas et al., 2014).

Teacher can create a problem-solving circumstance in the context of real-world situations by designing task and questions that correspond to either PjBL or PbBL. PbBL, which tackles the real-world problems but does not necessary require students to conduct a project to investigate the problem. It could be completing a task, having group discussion and, of course, doing project. Whereas PjBL requires students to do a complex task, some form of presentations such as oral and poster presentations, as well as creating product, prototypes, or artefact.

2.8 Conceptualisation of Problem-Project Based Learning (PPbl) in this Study

In this study, researcher combines both the characteristics of PjBL and PbBL to formulate the inquiry-based learning method termed "problem-project based learning" (PPbl) as conceptualized from thorough and rigorous reviews of both inquiry learning methods. Figure 2.1 shows the concept of PPbl in this study.

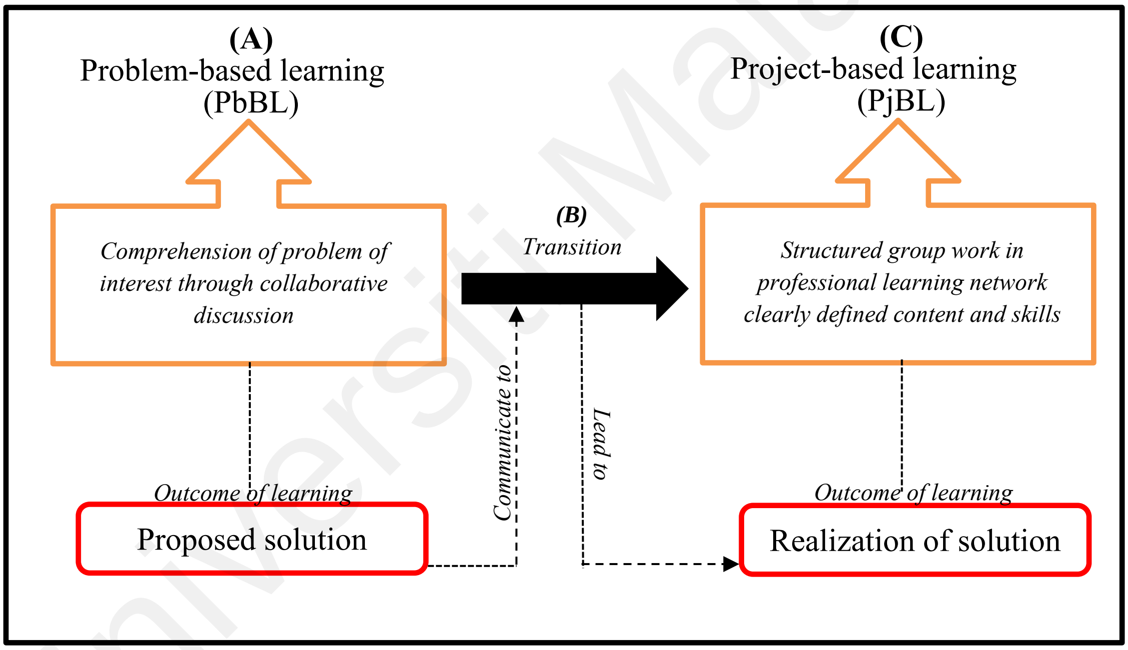

Figure 2.1 Concept of Problem-Project Based Learning (PPbl) in this Study

The concept of PPbl can be explained as "turning a *problem* into a *project*". There are three phases (A, B and C) in PPbl. In phase A of problem-based learning, students need to first identify the topic of interest that they need to be studied that serves as the "problem" and propose the solutions that is feasible to be investigated, which as prescribed in one of the characteristics of PbBL. The problem must be one of the issues to be solved in real-world. The comprehension of problem of interest through collaborative discussion generates proposed solution as learning outcome (Tse & Chan, 2003).

Phase B is the transition of ‘problem’ into a ‘project’. It involves the planning on the execution of the proposed solution. In this study, the design of project prior to problem was done within the context of authentic tasks and settings prior to discuss with scientist and teachers, which can be termed as fostering scientist-teacher-students collaboration (STSC).

In phase C, students need to carry out the PjBl on the problem posed with scientist and teachers for prescribed weeks or months. This phase involves structured group work in professional learning network clearly defined content and skills (Barron & Darling-Hammond, 2008; Ertmer & Simons, 2005; Mergendoller & Thomas, 2005; Hung, 2008). This phase leads to the realization of proposed solution which might create deeper understanding about the problem or concrete prototypes of products.

2.9 Bales’s Interaction Research and Process Analysis

There were two traditions of interaction research: Bales’ Interaction Process Analysis (IPA) with Sacks’ Conversation Analysis (Peräkylä, 2004). Balesian tradition used quantitative approach to study the functioning and the structure of a small group interaction, whereas in the Sacksian tradition used qualitative approach to examine the structures and practices of human social interaction. In this section, the Balesian IPA model will be discussed as the data analysis method used in this study.

Bales’ model of IPA (1950) serves as the model for observing and understanding social interactions. The tradition of IPA research (1950) employed quantitative analysis to examine human interaction. Researcher is responsible to find out the frequency of individual’s actions, behaviours and reactions belonging to each category occur in the context that has been examined, including the frequency of fitting acts into different categories, different positions in relation to each other among participants and reasoning how these acts belong to their respective categories. This contributes to the understanding of distinct character of the group, including different phases of activity and differentiation of the roles of participants during interaction (Bales, 1953; Bales & Slater, 1956).

The notion of interaction research developed by Bales (1950) stated that the researcher categorised the human behaviours observed from social interaction by "sitting and watching people as they are talking and write down categories of what they are doing as they're doing it" (Sacks, 1992, p. 28). Initially, IPA was developed for examining problem solving discussion groups set up for research purposes in a laboratory setting. Later, this method was used in research on various types of small groups face-to-face interaction, including naturally occurring ones (Bales, 1953; Eskola, 1961). Thus, in this study, researcher used participant observation to collect the data of small learning group interaction between scientist, teacher, and students during STSC-PPbl as one of the suitable methods to adopt IPA as supported by Manstead and Semin (2001).

IPA proposes twelve numbers of categories which can be divided into two areas: neutral tasks areas (attempted answers and questions) and socioemotional areas (positive and negative reactions) as shown in Figure 2.2. The outcome of the analysis attempts to abstract the raw data from observations to produce a picture on total on-going process. The set of twelve categories and the actual behaviour which is classified under them are brought into working relation to other bodies of theory related to larger social systems (which is not discussed in detail in this section).

Besides that, Bales (1950) illustrated six subareas associated with interlocking functional problems which are logically applicable to any concrete type of interaction system namely subareas of orientation, evaluation, control, decision, tension-management, and integration as shown in Table 3.8. These subareas are related to a hypothetical conception of problem-solving sequence of interaction for two or more persons. Bales (1950) posited that IPA is an over-simplified view, yet this model helps the researcher illustrate the interactive relationship that may appear under certain conditions.

In this study, IPA was adopted to analyse the interaction between scientist, teacher, and students during PPbl process. This is because it has the advantage of, very often, allowing the statistical treatment of various forms of interactions (including behaviours and conversations) while yet retaining its grosser meaning. The attempt of using IPA made by researcher as data analysis framework intended to yield and explore content of interaction among the participants in this study and allowed the emergence of new insights or theme to supplement the existing areas of analysis. In short, this framework allows blending of major qualitative approach and simple quantitative treatment of interaction data in this study.

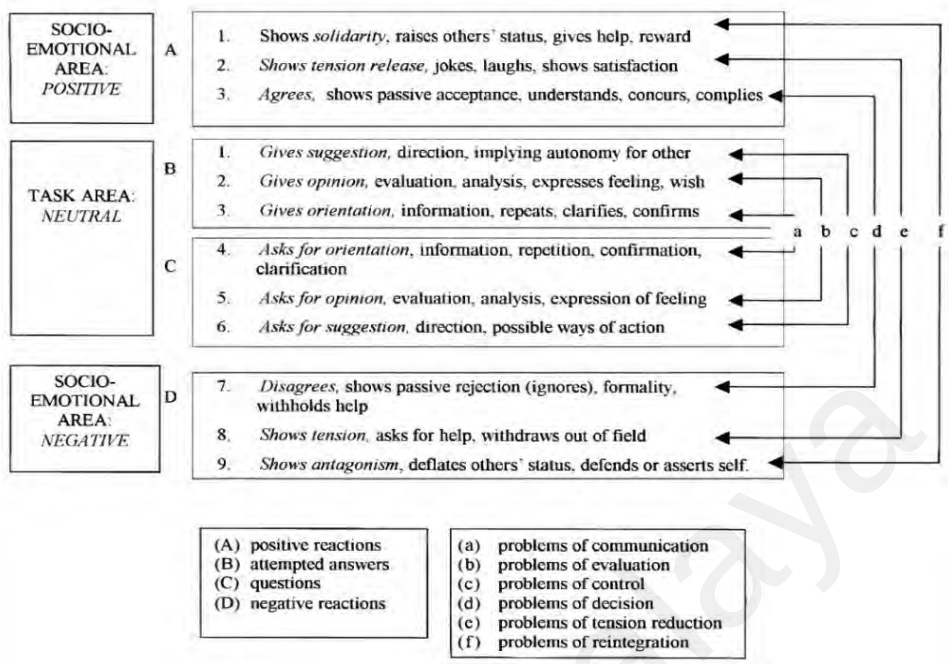

Figure 2.2 The system of categories used in IPA (Bales, 1950)

2.10 Theories Underpinning the Study

In this study, researcher used sociocultural perspective to provide richer and in-depth description of the interactions during the STSC-PPbl in authentic research setting. The theoretical framework that guides the researcher to explore the interaction between scientist, teacher and students in this study is based on situated cognition theory supported by Vygotsky's social constructivism theory.

2.10.1 Situated Cognition Theory

Situated cognition theory, as proposed by Brown et al. (1989), asserted that the learner constructs the knowledge within the context, activity, and culture in which he or she learns. It models the way of individual learns in the context of interaction within the social being. This theory argues that process of learning is social and not isolated, i.e. individuals take part in learning by interacting with each other through shared activities and language, discussion, and problem-solving processes. In this study, students were placed in a research laboratory which is an authentic science context to interact with both scientist and teacher through various activities such as conversation, discussion and executing experiments in a PPbl.

This theory is supported by the concept of cognitive apprenticeship as proposed by Brown, Collins, and Newman (1988). Cognitive apprenticeship is one of the pedagogical implications of situated cognition theory. The term 'apprenticeship' signifies two important characters which are significant in learning process, "novice learner" and "expert". In this study, scientist is the scientific research "expert" and students are the "novice learners". Researcher posited "teacher" as science education "expert" but could be scientific research "novice learner". The novice learns important skills, interactions and experience shared by experts as an apprentice. Expert passes down the methods and traditions which the apprentice can learn only from the expert which are authentic learning. Cognitive apprenticeship is a form of sociocultural approach of learning, which also refers as "authentic learning". Expert is considered as the regular and skillful practitioner in everyday life who can scaffold the novice to develop more sophisticated level of skills and knowledge through social interactions.

Situated cognition theory helped researchers to gain deeper understanding on the process of how people learn because it focused on what people learn in their everyday lives, which are authentic contexts for a variety of skills. Furthermore, it allows educators to understand the methods to assist their students to learn new concepts and skills based on their prior knowledge and skills that their students may already have. In this study, the authentic context refers to the research laboratory in a research institute where scientists practiced scientific investigations. Based on this theory, by situating students into this context, rather than science teaching laboratory in school, could give impact on the science learning by students.

Lave and Wenger (1991) argued that learning environments are often characterised as authentic to the extent as they engage the students in real world, situated activity. This theory shed lights on the explanation for the interactions between experts and novices, which offer access to "participation in socially organised practices, through which specialised local knowledge, rituals, practices and vocabulary are developed" (Hennessy, 1993). The theory views learning as a social activity where individuals develop the knowledge, skills, language, and customs of a discipline through interacting with other individuals of the discipline including peers and experts (Lave & Wenger, 1991). In this study, scientist, teacher and students were viewed as a learning community in a social structure. Science knowledge, skills and communication through scientific language would be developed during interactions between students and scientist in authentic research context.

Cognitive apprenticeship refers to the processes and experiences through which novices develop cognitive skills required to perform in a certain discipline as they work closely with the expert (Collins, 2006). The learning experience studied here was designed as an operationalization of these theories and with features of authentic learning environments in minds (Dolan & Grady, 2010). In this study, cognitive apprenticeship refers to students could gain science knowledge and procedural skills when working closely with scientist to conduct scientific investigation in a research laboratory.

2.10.2 Vygotsky's Social Constructivism

Vygotsky's theories asserted much on fundamental role of social interaction in the development of cognition, i.e. community plays the roles in helping individual to make meaning for learning (Vygotksy, 1978; Tudge & Scrimsher, 2003). Vygotsky believed that interactions between the individuals in the environment such as apprenticeship and collaboration could stimulate the developmental process and promote cognitive growth of individuals. The social interaction is useful in helping learners to transform their experience based on knowledge and characteristics and reorganise their mental structures. (Vygotsky, 1978), i.e. the way of interactions between learner and other learners, objects or institution. In this study, the collaboration and apprenticeship between novice (students) and experts (scientist and teacher) in working a project in a research environment to explain the gist of this theory. Based on this theory, students were expected to experience the interaction together with scientist and teacher and transform the experience into gain in science knowledge and procedural skills based on their prior knowledge.

Vygotsky (1978) claimed that cultural tools in social interactions and the results of internalisation and mental transformation of the social interactions could help learner to undergo cognitive change. Vygotsky positions language as the most critical tool for development of cognition in learner. Once this process is mastered, the next step would be using this symbol to self-regulate thought and actions. In this study, scientist as one of the representatives of scientific community could interact with students with his or her own working culture and scientific language. Such culture and language during interaction were viewed as components to regulate science learning by students in this study.

Another key component asserted by Vygotsky's learning theory is mediation. Mediation refers to people intentionally interject items between their environments and learners; thus, they can modify it and benefited from the modification. The use of mediators (such as language, activity) helps human to change their environment for more beneficial purpose. It can also refer to the use of certain tools within socially organised activity (such as apprenticeship and collaboration). In this study, all the participants (scientist, teacher, and students) could mediate the interaction to achieve their own goals of benefitting themselves. For instance, teacher could take initiative to maximise the interaction between scientist and students to achieve the goal of optimum science learning by students. Students could ask questions to raise their understanding on procedural knowledge delivered by scientist during the interaction.

There are two important principles in Vygotsky's social constructivism namely More Knowledgeable Others (MKO) and Zone of Proximal Development (ZPD) as discussed below, which are the components used in developing theoretical framework to interpret the interactions during STSC-PPbl in this study.

2.10.3 More Knowledgeable Others (MKO)

MKO refers to someone who has a better understanding or a higher ability level than the learner, with respect to a particular task, process or concept. Vygotsky (1978) claimed that much important learning takes place through social interaction with MKO. MKO may model behaviours and/or give verbal instructions for the learner. The learner seeks to understand the actions or instructions provided by the tutor then internalizes the information, using it to guide or regulate their own learning process. In this study, both scientist and teacher were MKOs to interact with students in this study.

2.10.4 Zone of Proximal Development (ZPD) and Scaffolding

The concept of MKO is integrally related to Zone of Proximal Development (ZPD), the second important principle in this theory. ZPD is defined as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978). It represents the amount of learning possible by a student given in an instructional condition (Puntambekar & Hubscher, 2005). In the ZPD, expert works together with novice on a task completion that the novice could not perform independently due to the level of difficulty. In this study, the ZPD of students could be the lack of proper scientific research skills and knowledge at the initial stage and expected to develop with the guidance and collaboration from scientist in PPbl in this study. Figure 2.3 shows the visual representation of ZPD.

The emergence of ZPD has concurrently emphasised the importance of guidance provided by MKO to the development of skills and knowledge by novice learner. This form of guidance can be considered as *scaffolding* (Wood, Bruner & Ross, 1976). Bandura's (1986) participant modelling technique defined *scaffolding* as the efforts made by expert to model a skill, provide support and gradually reduce assistance given as learner develop the skill. It is suitable to scaffold students when expert provide novice learners with some information or to complete part of tasks for them so that they can stay attentive on the part of the task they are attempting to master. Eventually, students will assume responsibility for the development of skills or knowledge throughout the learning process (Moll, 2001).

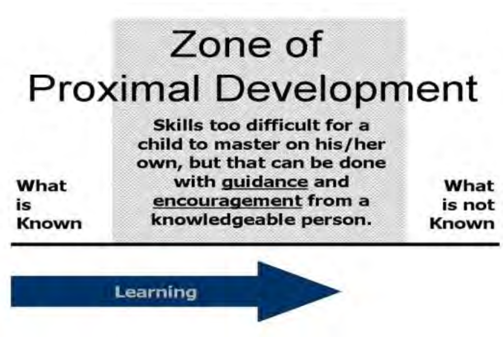

Figure 2.3 Visual representation of Zone of Proximal Development (ZPD).

2.11 Theoretical Framework in this study

The theoretical framework as shown in Figure 2.4 guides the answering of research questions in this study. In this study, based on situated cognition theory, STSC could promote the developmental process and cognitive growth of students by situated them in the context of research environment which will provide authentic science engagement. Knowledge is co-constructed by students during the learning process with scientist and teacher. The 'apprenticeship' in this framework signifies two important characters in PPbl, students as "novice learners", and scientist and teacher as the "expert" (Note: sometimes, teacher can also act as "novice learner" too). Students acquired important skills (such as laboratory handling skills, design of experiments, practical works etc.) and have interactions with both scientist and teacher (having face-to-face conversation and discussion) in this context. This theoretical framework guided this study to gain in-depth understanding on the process of interactions during STSC-PPbl (cognition) in this study, because it focuses on the functions of scientist and teacher act and how students interact with them in authentic research context (situation). In addition, this study also explores the strategies used by scientist and teacher to interact with students to acquire new concepts and skills based on their prior knowledge and skills that they may already have.

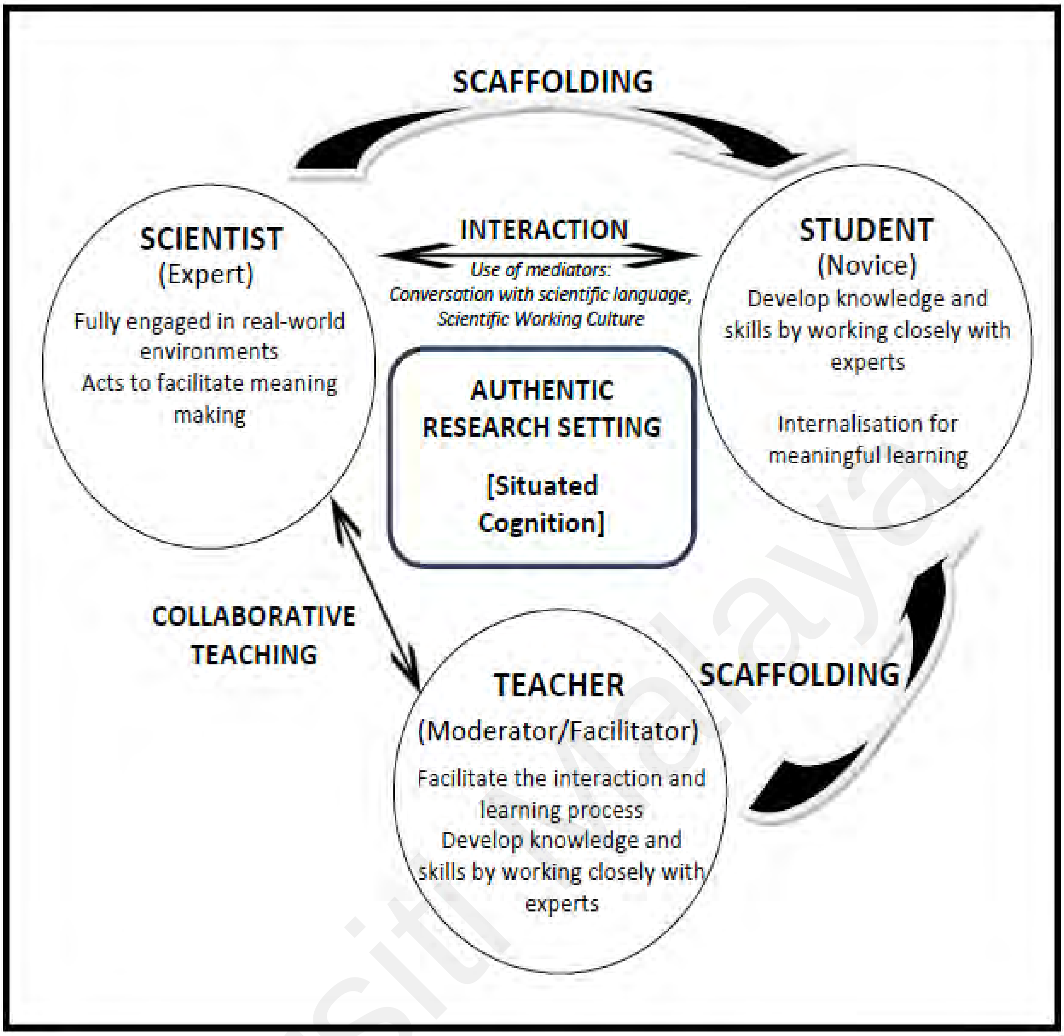

Figure 2.4 Theoretical framework used in this study based on situated cognition theory and Vygotsky social constructivism.

The learning environment is crucial for learning process to take place, especially for authentic science learning environments in situated cognition theory. Theoretically, students should be maximally engaged in real-worlds situations. This makes the learning of science becomes meaningful, as they believe that the knowledge of science learnt in classroom could be applied to understand the world better, as well as proposing plausible solutions to solve the problems exist to improve the quality of human well-being in whole. Based on situated cognition theory and Vygotsky's theory, researcher would like to explore and construct description on the interactions between experts (scientist and teacher) and students (novice) in this context. This context of study is set with developed science knowledge, traditions of scientific method and investigation practices, as well proper form of science communications which shape the working culture that engage students in learning process. Based on Vygotsky's theory of social constructivism, this framework believes that cognitive growth of students can be influenced through the STS interaction in this working culture. Students would use the information obtained through language and symbols during interaction to self-regulate thought and actions to develop science knowledge and skills in this context.

In this study, the CL processes take place as a social activity where scientist assists students in developing science knowledge, practical skills, language of science communications customs of a scientific field or discipline through interacting with students based on Vygotsky's social constructivism. Cognitive apprenticeship emerges in STS relationship when students develop skills required to perform in an authentic scientific investigation as they work closely with the scientist and teacher. This interaction assists students to transform their experience based on knowledge and characteristics of STSC-PPbl process, reorganize their prior knowledge to construct new knowledge in the context of real-world situations.

In this context, scientist is considered as the regular and skillful scientific method and knowledge practitioner that can scaffold the students to develop more sophisticated level of skills and knowledge through social interactions in this context. In other words, scientist serves as the MKO during the collaboration in this framework. Scientist plays role in modelling learning process and behaviors of students, deliver verbal instructions to carry out practical works, and having discussion with students throughout STSC-PPbl interaction. Scientist passes down the methods and traditions which the students can learn only from the scientist which are authentic learning. Students attempt to understand the actions or instructions provided by scientist then internalizes the information, using it to guide or regulate their own learning process in this study.

In this study, the function of teacher is considered as the facilitator or mediator of collaborative interactions between scientist and students in this context based on Vygotsky's social constructivism. Teacher plays role in facilitating and mediating the interactions between scientist and students, as well as maximizing the direct or face-to-face interactions to provide maximal engagement of students with the acts of scientist. The process of mediation done by teacher could maximize the beneficial effects of the apprenticeship and interactions between scientist and students in this framework. Teacher can also use language and physical signs to promote the collaborative interactions between scientist and students, as well as students can use language and physical signs to make use the collaborative interactions to perform more psychological functions between their minds and their research environments, as well as developing higher order intellectual capabilities.

According to Vygotsky social constructivism, there is a difference in a level of sophistication and ability in term of problem solving and independency in carrying out authentic investigation in PPbl which termed as ZPD. In this framework, the involvement of scientist and teacher in guiding students to perform scientific investigations (team teaching) could produce cognitive changes in ZPD. Students internalizes the cultural tools (working cultures) shared with scientist (interactions, research environments, learning experience and science communications) to produce cognitive change in the ZPD. Both scientist and teacher provide support and assistance to students at the beginning stage of practical works and discussion, and gradually lessen the “amount” of assistance given as student develop the skills in this study. The concept of scaffolding provided by scientist and teacher in this study depicts the effort made to shape and support students instructionally through various stages of skills acquisition. Scientist can provide students some information or to complete part of practical works with the guidance of scientist so that students are given sufficient time to understand the skills or knowledge they attempt to master and stay attentive. This does not mean that student learns passively during the guidance. During the progression of learning process, students will take the responsibility with less guidance from scientist to develop the skills or knowledge. Students actively acquire the knowledge by bringing their own understandings during the interactions and actively reflect on their own learning process. Thus, the reflective practice in this study supplements construction of new knowledge and skills acquisition during the process of STSC-PPbl interaction.

2.12 Summary

This chapter had reviewed relevant literatures related to collaboration, partnerships in science education, and IPA. Researcher had conceptualised the gist of the literatures to the concept and context of this study to understand the interaction process of STSC-PPbl in authentic research setting. Situated cognition theory and Vygotsky’s social constructivism serves as the foundations to construct theoretical framework in this study.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This study aims to explore the interaction during scientist-teacher-students collaboration in problem-project based learning (STSC-PPbl) in authentic research setting, as well as structural exchange pattern throughout the process of interaction. This chapter describes the methods and procedures involved to answer the research questions in this study as presented and discussed in the following sections.

(a) Research design

(b) Participants of study

(c) Programme context of STSC-PPbl

(d) Data collection techniques

(e) Data analysis

(f) Procedures of actual study

(g) Preliminary study

(h) Researcher's biases and assumptions

3.2 Research Design

The research design of this study is basic qualitative-exploratory study. Researcher used this research design to explore the interaction of scientist-teacher-students collaboration in problem-project based learning (STSC-PPbl) in authentic research setting. In addition, the study on interaction demonstrated certain extent of complexity and intricacies which suited the nature of this research design.

Although this study adopted qualitative research design, however, the quantification of qualitative data from this study was done to picture the structural exchange pattern of interaction of STSC-PPbl in this study based on the method adapted from Bales (1959) and Fahy (2001). The interaction pattern produced from quantification of qualitative data of interaction elements from observation notes triangulated by reflective journals written by students help researcher to gain general viewpoint on pattern of how scientist, teacher and students interact among each other and indication of “degree of involvement” qualitatively of each participant in this setting during science learning.

3.3 Participants of the Study

The participants were purposively selected in this study. Thus, the purposive sampling is useful if a researcher wants to investigate “a small subset of a larger population in which many members of the subset are easily identified but the enumeration of all is nearly impossible” (Babbie, 1990). The participants of this study involved one scientist (science research officer) in a research institute located in Selangor, Malaysia and four Form Five Science, aged 17 students, with one Chemistry teacher (the researcher himself in this study) from an independent high school located in Kuala Lumpur, Malaysia.

Four aged 17 students who took part in this study were selected through purposive sampling on voluntary basis. Researcher first listed out the criteria in three categories named fundamental skills, personal characters and interpersonal skills that should the students possessed to participate in this study as shown in Figure 3.1. However, the purpose of setting these criteria was to assess their readiness in general for subsequent guidance and motivation to participate the STSC-PPbl. Researcher gave emphasis on the strong interest to conduct research as priority for selection. These sets of criteria were not exposed to students as researcher would like to observe the natural interaction of students in STSC-PPbl in authentic research setting in this study.

Fundamental skills

- Oral presentation
- Writing
- Computer skill

Personal characters

- **STRONG INTEREST**
- Humble
- Inquiring
- Attentive
- Unafraid of setbacks
- Empathy

Interpersonal skills

- Sociable
- Willing to shoulder responsibility with others
- Take initiative to discover relation or opportunity from information

Figure 3.1 Three categories of criteria to recruit students in this study.

Researcher conducted a face-to-face interview and briefing session, as well as prolonged observation and engagements with four students before ascertained the recruitment. Researcher explained the process of STSC-PPbl of this study and the expected scientific attitudes they should possess while conducting the research project to students. These students demonstrated interest and have sound scientific knowledge in secondary level as well as good track record of academic performance in science subjects in school-based summative assessments. Coincidentally, all four of them were considered higher ability students with average score between 80-100 in school examinations.

A science research officer, the scientist in this study was invited to join this PPbl after the team (one teacher and four students) was formed with identified topic of interest. Scientist graduated with a Master of Food Science in a public university and currently working in a government research institute located in Selangor, Malaysia for more than seven years. She is specialized in bioactivity study (especially in antioxidant capacity study). The science research officer is regarded as 'subject matter expert' in this study.

The researcher himself served as the ‘teacher’ in PPbl in this study. He had more than three years of experience implementing science project-based learning and currently working as a Chemistry teacher in an independent high school. The function of the teacher serves as the ‘facilitator’ and participant observer to observe and maximise (when necessary) collaborative interaction between scientist and students in this study. In this study, all names are pseudonyms as shown in Table 3.1.

Table 3.1

Participants of authentic research problem-project based learning in this study

Participant(s)	***Pseudonym(s)***	***Background***
Scientist	Sharon	Female, master’s in science, A researcher who work in a research institute for eight years.
Teacher	Ben	Male, Bachelor of science, A Chemistry teacher who has the teaching experience of 3 years.
Students	Thomas Tom Mark Clark	Male, Form Five science stream students, High-achieving performance

3.4 Programme Context of STSC-PPbl in the Study

It is necessary to depict the context of this study to describe the background, environment, setting, framework, or surroundings of STSC-PPbl to understand the process of interaction took place in this study. The following section revealed the programme context starting from implementation of collaboration and detailed procedures of phases of PPbl in this study.

3.4.1 Implementation of STSC-PPbl

This STSC-PPbl took one and a half (1.5) years to complete, including data collection and analysis to answer the research questions in this study. STSC-PPbl interaction adopted unstructured collaboration for two months to study the antioxidant capacity of hot spring algae. Unstructured collaboration involved planning but there are no strict rules in collaboration sessions. Teacher as the researcher in this study first explained the anticipated roles of scientists as mentors, teacher as facilitator and students as learners to the respective participants. The participants (scientist, teacher, and students) were given freedom to execute their functions and flexibly interact in this collaboration. Researcher then observed the interaction took place.

In actual study, there were three phases of STSC-PPbl as shown in Table 3.2. The first phase was the problem-project design which involved bipartite collaboration (collaboration involves only two types of parties) either between scientist and teacher or teacher and students; the second phase was the practical works and experiments involved tripartite collaboration (collaboration involve only three types of parties) between scientist, teacher and students in doing practical works and experiments with respect to the proposed solution of the problem; while third phase was communicating results and reporting involved bipartite collaboration either between scientist and teacher or teacher and students to analyze and interpret the data collected from second phase, and then communicate the results to the public *via* poster presentation and participation in international science fair.

Table 3.2

Three phases of PPbl in this study

Phase	*Parts of Activities*	*Duration*	*Involvements of participants*	*Mode of partnership*
(1) Problem-project design	• Part 1: Crafting problems	20 weeks in total (approximate 5 months)	Teacher and students	Bipartite
	• Part 2: Designing project and cultivating partnership		Scientist and teacher	Bipartite
	• Part 3: Infusion of projects prior to problems		Teacher and students	Bipartite

Table 3.2 (continue)

Phase	*Parts of Activities*	*Duration*	*Involvements of participants*	*Mode of partnership*
*(2) * Practical Works and Experiment*	• *Activity 1: Preparation of hot spring algae sample* • *Activity 2: Ethanolic extraction of hot spring algae* • *Activity 3: Aqueous extraction of hot spring algae* • *Activity 4: Antioxidant capacity study of hot spring algae extract*	*3 weeks (6 days of interaction)*	*Scientist, teacher, and students*	*Tripartite*
(3) Communicating results and reporting	• Data analysis and interpretation • Oral presentation • Poster presentation • Participate in science exhibition (international)	20 weeks (approximate 5 months)	Teacher and students or Scientist and teacher	Bipartite

* The focus of this study

However, the observations on STSC were only made in Phase 2. This is because the STSC was fostered when the problem was properly framed by teacher and students, and further reviewed by scientists before reaching consensus on school-research institute collaboration. This tripartite collaboration was the key area of this study to answer the research questions. The term *tripartite* illustrated students worked together with scientist and teacher in general in PPbl in the context of this study. At instant, student could work along with scientist with or without teacher to solve problems in PPbl, or perhaps sometimes students work among themselves. These contents and patterns of tripartite interactions were the focus in this study.

Also, the researcher found that the duties of teacher and scientists, as well as schooling period of students make it difficult for them to allocate time and space to foster the partnership. Therefore, it is necessary for researcher to carefully plan the data collection activities in the second phase because there has been challenges in scheduling a dedicated collaboration between scientist, teacher, and students. To lessen the disturbance on the schooling period of students, the tripartite collaboration was made during school mid-term break as prescribed in MoE academic calendar. However, the use of technology such as *Facebook* and *Whatsapp* Messenger improved the communication strategies for teacher and scientists, especially during the PPbl design in phase one.

3.4.2 Detailed procedures for Phase One: PPbl design

To conduct STSC-PPbl, students must first select the topic of interest to be studied. In this study, the research problem (or 'problem') must be properly framed first and lead to selection of topic of interest before fostering collaborative relationship with scientist from relevant research institute. In this section, the detailed procedures for phase one (problem-project design) is delineated which then subsequently will lead to the happening of collaborative interactions in phase two (practical works and experiments). Figure 3.2 shows the detailed description of parts of activities in phase one

Phase 1: Problem-Project Design

Part 1: Crafting problem (students and teacher)

- Understanding real-world problems
- Selecting specific real-world problem to solve
- Justifying selected problem
- Forming initial problem statement
- Proposing solution

Part 2: Designing project and cultivating partnership (scientist and teacher)

- Formulating problem statement and solution
- Designing flow of project based on problem statement and solution
- Forming partnership between school and research institute
- Identifying prior knowledge required for the project

Part 3: Infusion of knowledge prior to problems (students and teacher)

- Topic 1: Introduction to research methodology and scientific attitude
- Topic 2: Introduction to organic chemistry
- Topic 3: Introduction to natural products and its chemistry
- Topic 4: Chemistry behinds antioxidant capacity
- Topic 5: Directed reading of literatures

Figure 3.2 Detailed description of phase one (crafting problem) in this study.

3.4.2.1 Crafting problem

After being exposed to scientific methods and advanced projects guidelines, teacher and students worked on crafting problem for PPbl in this study. The process of crafting problem was not easy and was guided by the protocol developed by Mohd Yusof, Jamaludin, Harun and Syed Hassan (2012). According to Mohd Yusof *et al.* (2012), there are five important and interrelated principles in crafting effective problem in PBL include authentic and realistic, constructive, and integrated, suitable complexity, promote self-directed learning and lifelong learning and stimulate critical thinking and metacognitive skills. Students shall select the topic of study based on their curiosity, observation from real-world context and interest. This would make students to become intrinsically motivated to learn, as well as making them to be self-directed and lifelong learners (Ceker & Ozdamli, 2016; Cindy & Hmelo-Silver, 2014).

Students were first encouraged to expose themselves with real-world issues that surrounds them. Then, they began to select the fields they would like to study. To organize the real-world issues into fields of study, the students were introduced to the concept of mind-mapping as shown in Figure 3.4. Researcher required the students to deductively narrow their research scopes and get their topic of interest to be more specific and well-defined along the mind-mapping process. Practically, students first stated the core topic of their interest named “green science and waste”. Then, they listed out the keywords related to “green science and waste” and further searched more information regarding the keywords. After few days, all the students met the researcher and presented the information they found related to this keyword. After listening to their peers’ presentation, they chose one of the subtopics under the core topic. Then, they focused on the subtopic chosen and keep on searching for more information and issues that need to be resolved. After evaluating each issue, students chose one of the desirable topics with feasible proposed solution as the topic of the PPbl. This method kept the ideas organized and deductively gains the idea of project with well-defined research problem statement. Figure 3.3 showed the narrowing and selection of research area selected by student through mind-mapping from the topic of green science and waste.

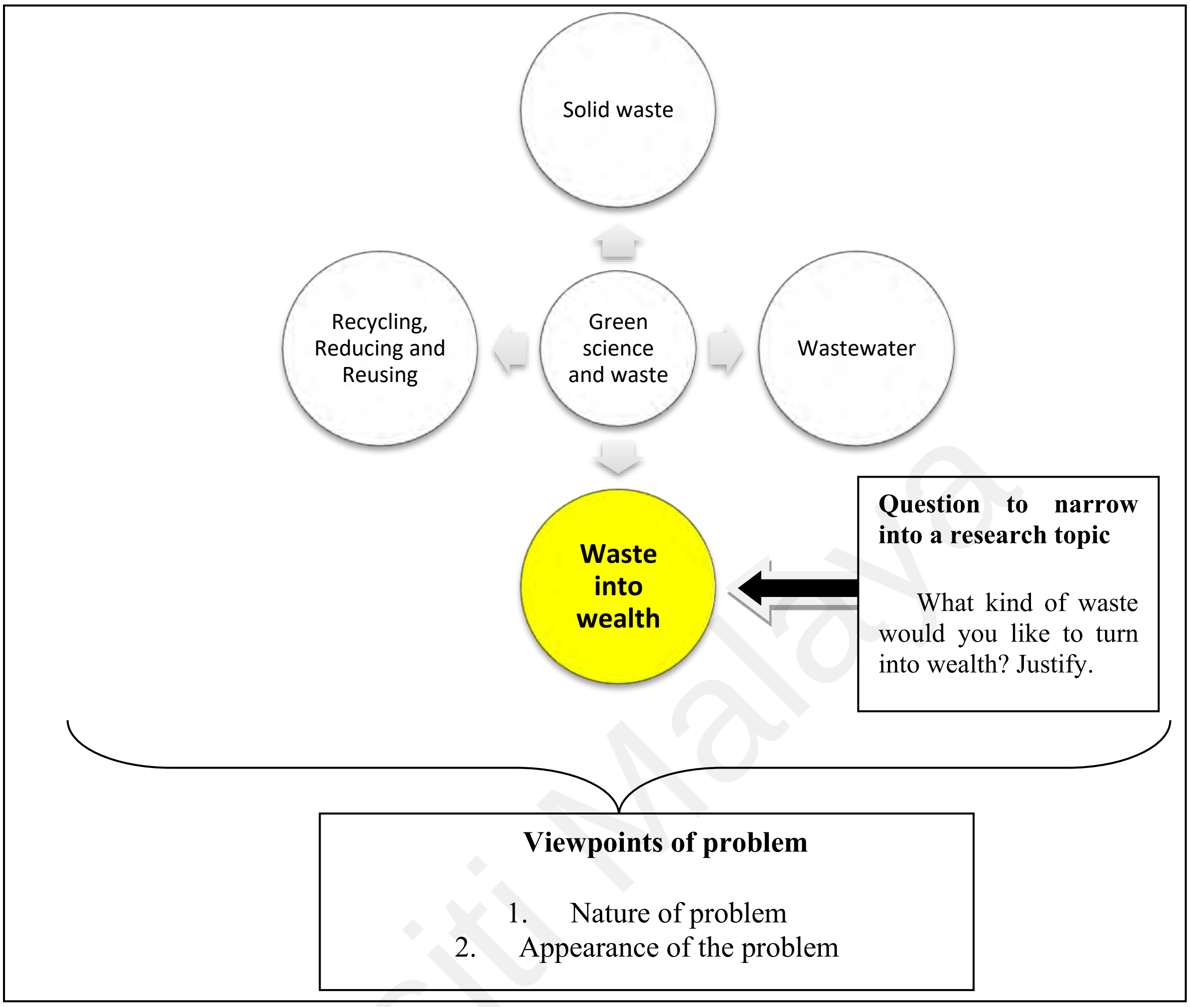

Figure 3.3 Mind-mapping integrated with viewpoints of problem in searching project ideas in this study.

Two areas were introduced to view the problems namely 'the nature of the problem' and 'the appearance of the problem'. The *nature of the problem* refers to "how this issue becomes the problem from the angles of knowledge and value?" and the *appearance of the problem* refers to "what are the concepts and variables involved in the problem yet to be solved and answered?". These areas helped teacher and students to formulate, evaluate and narrow the scope of the problem, as well as cultivating the reading and comprehension skills and critical thinking skills of students. (Note: these two skills were not measured in this study).

3.4.2.2 Designing project and cultivating partnership

The partnership was fostered through the official visit by delegates from an independent high school in Kuala Lumpur where affiliated with the researcher (teacher) and students in this study to a research institute located in Selangor, Malaysia. Before the official visit, researcher personally met the scientists to discuss the scope of the projects related to the therapeutic effect of the plant. Few scientists designed the project with teacher by taking the following aspects into account:

a) Duration of project

Allocating and managing the duration of the project in this study was not easy. The project was executed during midyear school break according to academic calendar as prescribed by MoE. After having discussion with both school and research institute, the time allocated for collaboration in this PPbl was working days (Monday to Friday) within two weeks, from 9 a.m. to 4 p.m. However, students and teacher came to the laboratory in accordance with the progress of the practical works.

b) Level of difficulty of project

There were three scientists assigned by the research institute to discuss from which topics student shall study the properties of hot spring algae. The properties of hot spring algae shall be studied from the perspectives which could elicit the ideas for potential applications of aqueous and solvent extract of hot spring algae. Each scientist has different areas of expertise. Therefore, there were three perspectives (biological activity-antioxidant capacity, in-vitro toxicity, and phytochemical constituents) suggested by scientists as depicted in Table 3.3.

Table 3.3

Three topics of studying properties of hot spring algae as suggested by scientists.

Topics		Description	Method of Study / Bioassay
(1)	Biological activity-total antioxidant capacity	Total antioxidant capacity (TAC) is an analyte frequently used to assess the antioxidant status of biological samples and can evaluate the antioxidant response against the free radicals produced in each disease (Rubio *et al.*, 2016)	2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, cupric reducing antioxidant capacity (CUPRAC) assay
	Quantification of phytochemicals	To find out the quantity of phytochemicals/bioactive compounds that contribute to the total antioxidant capacity of extract	Total phenolic assay (TPC), Total flavonoid assay (TFC)
(2)	In-vitro toxicity	In vitro toxicity testing is the scientific analysis of the effects of toxic chemical substances on cultured bacteria or mammalian cells. (Roggen, 2011)	3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) assay
(3)	Phytochemical constituents	Phytochemical screening refers to the extraction, screening and identification of the medicinally active substances found in plants.	Tests for alkaloid, saponin, flavonoid etc.

The level of difficulty, or complexity of the topic of PPbl was taken into consideration during the discussion between scientists and teacher in term of cognitive, psychomotor, and affective domains. The topic selected shall be suitable for secondary school students to engage. In term of cognitive domain, the topic selected should construct more advanced knowledge based on their prior knowledge learnt in Additional Mathematics, Physics, Biology and Chemistry and relevant to real life experience. Besides that, in term of psychomotor domain, students must be capable of carrying out the laboratory techniques as prescribed by the topic selected. The laboratory techniques involved in the selected topic should comprise the laboratory techniques that need to be learnt in SPM Biology and Chemistry syllabus, along with additional advanced laboratory techniques that need to be performed in this PPbl that might beyond the school syllabus. Lastly, the topic should make student feel more relevant to their science learning in classroom and their life for maximal engagement during the PPbl process.

After having the thorough discussion between scientists and teacher, the topic centered on the ‘Antioxidant Capacity Study and Quantification of Phytochemicals’ study of hot spring algae with the involvement of teacher and students. The selection of this topic was justified based on consideration as shown in Table 3.3. In term of cognitive domain of learning (knowledge), the content knowledge of this topic advances the science learning based on the prior knowledge of students. In term of psychomotor domains of learning (skills), the selection of this topic provides the opportunity to students to perform the practical skills learnt in Chemistry syllabus, besides developing new laboratory techniques and skills. In term of affective domain of learning (scientific values and attitudes), scientists and teacher presumed that students may or may not realize the importance of antioxidant in daily life. Table 3.4 depicted the speculated learning outcomes based on learning domains and prior knowledge required by students in this study.

Table 3.4

The speculated learning outcomes based on learning domains and prior knowledge required by students in this study

Domain	Justification	Prior Knowledge Required
Cognition	The selection of this topic advances the science learning based on the prior knowledge of students.	a) Chemistry Carbon Compounds, Chemicals for Consumers, Reduction and Oxidation a) Biology Chemical composition of cell b) Physics Wavelength, Electromagnetic Spectrum (For spectrophotometry in this study) c) Additional Mathematics Statistics

Table 3.4 (continue)

Domain	Justification	Prior Knowledge Required
Psychomotor	The selection of this topic provides the opportunity to students to perform the practical skills learnt in Chemistry syllabus, besides developing new laboratory techniques and skills as prescribed in this topic.	a) Chemistry Basic Skills in Handling Apparatus, Dilution, Reflux, Stock Solution Preparation
Affective	Students need to be given exposure on the benefits and importance of antioxidants in protecting cells against the effects of free radicals.	Students may or may not realize the importance of antioxidant in daily life

3.4.2.3 Infusion of knowledge prior to problems

This topic of PPbl involves various fields of advanced science knowledge such as chemistry of antioxidants, antioxidant capacity, bioactivity and bioassays involved in studying antioxidant capacity. All these knowledges are considered beyond the syllabus of SPM science curriculum. Teacher believed that students would have difficulties in understanding the core knowledge required in carrying out the practical works of PPbl in this study. Therefore, teacher provided training on the basic knowledge of the selected topic to students (participants) as required in this PPbl. Teacher provided the learning materials (such as journal articles and training notes) to students and asked them to read within eight weeks. To choose the appropriate learning materials, teacher first consulted the scientist and let scientist to review the learning materials before exposing them to students. Then, teacher conducted group discussion or lecture with students to learn the basic knowledge as required before interacting with scientist. Table 3.5 shows the content knowledge and respective learning materials during the training phase.

Table 3.5

Content knowledge and respective learning materials during the training phase

Topic	Content	Learning Material(s)	Instructional Method
(1) Introduction to Research Methodology *Duration: 2 Weeks*	- Introduction to scientific investigations - Directed reading (journal / research articles) - Referencing system	Online resources	Didactic lecture and questions, Discussion
(2) Introduction to Organic Chemistry *Duration: 2 Weeks*	- Homologous series and functional groups - Aromaticity in organic compounds	Online resources	Didactic lecture and questions, Discussion
(3) Introduction to Phytochemical Compounds *Duration: 3 Weeks*	- Introduction to Natural Product Chemistry - Secondary Metabolites (Alkaloids, Triterpenoids, Saponin, Flavonoid, Steroid)	Online resources	Didactic lecture and questions, Discussion
(4) Chemistry of Antioxidants *Duration: 3 Weeks*	- Introduction to Antioxidants - Antioxidant Capacity Bioassay	Online resources	Didactic lecture and questions, Discussion
(5) Directed reading of relevant journals *Duration: 2 weeks*	- Reading of academic research articles in journals	Research articles from academic journals	Discussion, Content analysis

3.4.3 Practical works and experiments

In phase two, scientist, teacher and students worked together to do practical works and experiments corresponding to the problem and solution as formulated in phase one, which involved tripartite collaboration. The collaboration took place for six days within three weeks, with approximate 40 hours of interaction in total.

There were four students, a teacher and a scientist involved in this collaboration. However, not all the students could fully attend the six days of collaboration due to some unavoidable personal occasions. Thus, it was a challenging task to cultivate the collaboration and face to face interaction between these three parties. Thus, it was crucial to remind students to get themselves clear about the whole process of phase two if they were absent on the particular day. Students were required to write reflective journals before or after the collaboration to serves as triangulation of the participant observation notes. This was one of the qualitative data sources.

In this tripartite collaboration, there were four activities that needed to be completed: (1) preparation of fresh hot spring algae sample; (2) ethanolic extraction of hot spring algae; (3) aqueous extraction of hot spring algae and (4) antioxidant capacity study of hot spring algae as prescribed during the discussion between scientist and teacher in designing this PPbl as shown in Figure 3.4. These four activities were not done in sequential manner and dependent on the progress and outcome of each activity. Two activities could run simultaneously, separately, or repetitively. One of the examples was the issue of amount of hot spring algae sample to suffice the practical works and experiments. Students and teacher might need to do sampling repeatedly if necessary.

Phase 2: Practical Works and Experiments [Scientist-Teacher-Students]

Activity 1: Preparation of Hot Spring Algae Sample

- Sampling of fresh hot spring algae
- Cleaning of fresh hot spring algae (wet sample)
- Preparing dry hot spring algae for phytochemical screening (drying and grinding)

Activity 2: Ethanolic extraction of hot spring algae

- Ethanolic extraction of hot spring algae (72 hours)
- Evaporation of ethanol solvent
- Transferring of ethanolic extract into clean bottles and cold storage

Activity 3: Aqueous extract of hot spring algae

- Reflux of wet sample of hot spring algae and water (2 times x 2 hours each)
- Filtration of aqueous extract

- Freeze-drying of aqueous extract and cold storage

Activity 4: Antioxidant capacity study of hot spring algae extract
Bioaasay used: 2,2-diphenyl-1-picrylhydrazyl bioassay (DPPH bioassay)
- DPPH assay for evaluating antioxidant capacity in ethanolic extract
- DPPH assay for evaluating antioxidant capacity in aqueous extract

Figure 3.4 Detailed description of phase two (practical works and experiments) in this study

3.4.4 Communicating Results

In phase three, students were required to communicate the results as the outcome of this PPbl as shown in Figure 3.5. Students would need to prepare a research poster which disclosed the results of study on properties of hot spring algae from the perspective of antioxidant capacity, in-vitro toxicity and phytochemical constituents and also prepare for communicating their results with community and experts through participation in STEM Project Expo to gain more insights and feedbacks from others regarding their project, which can serve as the recommendation for the expansion of study in future. Teacher had sought consent from the scientist of research institute to use the results of the PPbl for this purpose.

However, the research on phase three was not included in this study. This was because all the activities in phase three involved only bipartite collaboration, either between scientist and teacher, or teacher and students. The data analysis and interpretation were done by scientist and teacher, while poster presentation and participation in science exhibition was done by teacher and students. It was difficult to schedule the meetings between scientists, teacher, and students to collaborate in this phase due to duties of scientist and teacher and this phase was done during the schooling period of students.

Phase 3: Communicating Results

- Data analysis and interpretation
- Poster presentation

Figure 3.5 Detailed description of phase three in this study

3.4.5 Commitment of scientist, teacher, and students in PPbl

In this study, scientist served as the mentor for students. During the science research project, scientist engaged in one-to-group interactions about the design and conduct of their investigations, as well as their results, interpretations, conclusions, and recommendations for the further research. Also, scientist provided additional assistance *via* email, providing some information resources and journals for students to read, as well as description of the research at the outset of their research.

Researcher as the participant (teacher) in this research facilitated the collaborative processes between scientist and students, as well as ensuring students could develop knowledge or skills throughout the collaboration process along with scientist. Students played their roles as team member and academic scholar (Johnston, 2005). As a team member, students need to be willing to participate in the collaboration, build up the team, and learn teamwork. They need to subordinate their preferences to the objectives of the collaboration, and to work for the shared goals of the collaboration. Second, students also played their roles as "academic scholars" in PPbl. Students can be curious and question everything, as well as gaining in-depth understanding related to the research topic by taking in all sides of an argument and as much information as they can.

3.5 Data Collection

This study adopted basic qualitative-exploratory research design to unveil the interaction throughout STSC-PPbl in authentic research setting. The data collection methods used involved participant observation as primary data source and reflective journals written by students and memo written by teacher (researcher) as secondary data source for data triangulation.

3.5.1 Participant Observation

This study conducted a participant observation where researcher immersed himself into the setting and experienced the situation, i.e. interaction during the STSC-PPbl, observed and recorded the general view of atmosphere during the collaboration. Descriptive and reflective fieldnotes were recorded during the observation according to observation protocols (Refer Appendix A). This allowed researcher to be as involved as possible in experiencing the interaction during the collaboration as fully and as appropriate and manageable. Simultaneously, researcher needed to maintain an analytical perspective grounded in the purpose of observation note-taking. Thus, researcher needed to take reflective notes along with descriptive notes when conducting participant observations. The description during the interaction was recorded by observation protocol adapted from Howell's (1972) and Creswell (2007) method which consists of four components: establishing rapport, in the field, recording observations and data, and analyzing data (will be discussed in "Analysis of Data").

The identity of researcher as participant observer was revealed to other participants, i.e. scientist and students. Researcher had taken some actions to build rapport with the participants and environments before observation. Building rapport is important to assure the role of researcher as participant observer was well accepted by scientist and students during collaboration to collect data. First, researcher visited the laboratory in research institute and scientist before the collaboration started. This was to make the researcher familiar with setting before taking observation. Also, researcher had a conversation with scientist to understand her working style to assure smooth collaboration to take place. Second, researcher have built the rapport with students before the collaboration took place. Researcher knew the students two years ago before this study and have good relationship with them because researcher was their chemistry teacher for two consecutive years. Besides that, researcher had created a *Whatsapp* Group with all the students to stay connected with them, as well as giving them motivation and inspiration to participate in this research. Also, the researcher always reminded students to always stay loyal to their personal feeling and be honest about what they do, how they feel and what they think throughout the collaboration process. This was to obtain authentic data and responses from students.

The observation protocol adopted in this study was based on the protocol established by Howell (1972) and Creswell (2007, p.137) (Refer Appendix A). In this study, field notes are descriptive, thick, deep, and rich description on interactions during STSC-PPbl. The observations were carried out for six days within three weeks (including hours working in the laboratory) with average five hours per day (minimum 2 hours and maximum 7 hours per day). The interaction was observed by looking at the interaction between scientist, teacher, and students throughout the collaboration process, as well as the content of the interaction that took place. The observation protocol has been validated by a qualitative methodological researcher with more than 10-year experience. The protocol was preliminarily tested before administered to actual study as explained in "Preliminary study" section. The suggestions for improvement had also been discussed in that section.

In addition, researcher would like to stay neutral during the observation note-taking. This allowed the researcher to unveil information as maximal as possible and may lead to new, emerging themes and findings at the end of the research. The observation field notes taken would be cross validated with reflective journals written by students and participant validations for data triangulation. Also, during the observation, participant observer (researcher) needed to separate description from interpretation and judgement.

During the observation, researcher used his eyes, ears, perspective, and proximity for observing the interaction between scientist, teacher (researcher himself) and students. For first observation, researcher just jotted down the summary of conversation during interaction. To improve, for subsequent observation, the researcher attempted to listen attentively to their conversations and jotted them as original as possible (Refer Appendix B). Although researcher played his role as facilitator in this collaboration, researcher was aware of the necessity to allow natural interaction setting between scientist, teacher and students to take place and be observed in this study.

In this study, researcher found that observing the STSC interaction was a very challenging task. Researcher needed to record down all the actions, conversation, emotions, responses etc. made by scientist, teacher and students during the collaboration, and simultaneously researcher needs to take some actions such as asking questions to students was aware of what they were doing, checking students' understanding etc. during the collaboration. However, if researcher was facilitating the collaboration, it was difficult to observe the interaction took place. This could be considered the practical disadvantage of participant observation in this study. Thus, researcher needed to stay very alert to note down every event took place during the collaboration and recalled the events based on his memory after the collaboration. Besides that, researcher needed to re-read the observation notes and add up the missing parts. However, there was an ethical difficulty of researcher might misadd or misreport the "missing parts" as parts of the observation notes. Therefore, if there is any uncertainty in adding up the "missing parts", researcher needed to state them in the reflective notes for reference or validate them in future.

On the other hand, researcher found it was challenging to observe the interaction if there is division of labors or tasks (practical works) among the students. It means that, at the same time, students might be divided into two groups and assigned different tasks that related to a common goal. For example, to prepare an ethanolic extract of hot spring algae, some students were assigned to clean the algae, while another student followed the scientist to do the preparation such as taking out chemicals and cleaning apparatus for extraction. Researcher recognized that such division of labour in PPbl would result in student may have very different learning experiences. Such lack of "standardization" of learning experiences is a potential drawback of PPbl in this study (Johnston, 2005). To decide which event should be observed, researcher needed to prioritize the observation on interaction between scientist and students, while the observation on tasks related to sole interaction between students will be subordinated. The reflective journals written by students allowed researcher to obtain maximal and rich description on interaction take place.

3.5.2 Students' Reflective Journals

Reflective journals are individual records of students' learning experience in this study. The usage of journals has been used in exploratory education research which can benefit students beyond learning how to write. Students are required to think in depth, confront their own values and pose questions upon their thoughts. Also, this allows students to take charge of their own learning and develop the habits of reflective, lifelong learning.

Researcher used Rofle, Freshwater and Jasper's (2001) model of reflective practice, 'what?' refers to description on what happened objectively without further judgement, 'so what?' refers to description with some reflections such as feeling, ideas and analyses of the session and lastly 'what next?' refers to the decision made on thoughts and actions in the future because of this experience. Researcher integrated this model into designing reflective journaling protocols in this study as shown in Figure 3.6 (Refer Appendix F). The reflective journaling protocol has been validated by a qualitative methodological researcher with more than 10-year experience. The protocol was preliminarily tested before administered to actual study as explained in "Preliminary study" section. The suggestions for improvement had also been discussed in that section.

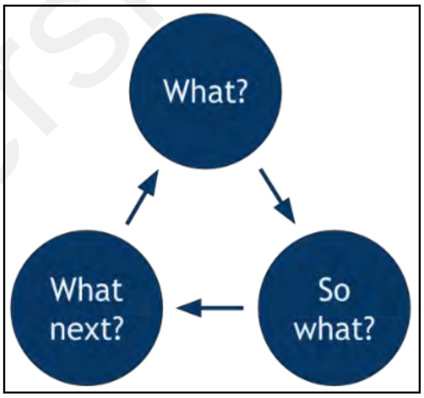

Figure 3.6 Rofle's (2001) model of reflective practice

Students were required to write reflective journals after practical work. Before writing reflective journal, students were given training on self-questioning using three simple questions and "thinking without further processing" method, i.e. once the thought emerges and they needed to record it down honestly without further processing those thoughts (Jones & Winne, 1992). Then, students were required to submit their first reflective journals, checked by researcher, and given feedbacks to improve their practices. Students could write informal reflective journal, i.e. they just write anything they experienced and felt straightforward without further processing and categorizing their thoughts. This is because researcher would like to obtain the first-hand primary data to perform coding and analysis.

Students wrote the journals after the collaboration sessions. Most of them submitted two journals after the sessions. It was an on-going process. Researcher always reminded students to be loyal to their expression during journaling as explained in "Preliminary study" section. Researcher kept on giving feedback to students on their submitted journals to improve their journaling technique.

Students wrote the reflective journal using their native language, Chinese language which allowed them to express their thoughts and ideas smoothly. The reflective journals were translated back-to-back into English version by researcher and validated by an English teacher who has teaching experiences of 3 years. Once validated and translated, the researcher went through the translation with students to ensure the students' detonations were not altered.

3.5.3 Reflection and Memo (Reflexivity of Researcher)

Personal reflection of researcher as participant observer in observing interaction between scientist, teacher and student in problem-project based learning is also an important part of this study (Refer Appendix H). This is because researcher needs to include his perception, assumption, and prejudices inadvertently while taking observation field notes, increasing the validity of the findings in this study (Roller, 2014). Simultaneously, researcher can also be aware of the preconceptions and biases in this study. The reflection analytic memo served as the reflection of the researcher before, during and after the collaboration, as well as provided audit trail for researchers during the qualitative analysis of data.

3.6 Preliminary study

The purpose of conducting preliminary study in this research is to assess the acceptability of observation and reflective journaling protocols. Preliminary study was carried out on the data collection techniques such as observation note-taking and reflective journals. Researcher involved himself as a participant observer and played his role as teacher in facilitating interactions between scientist and students in this PPbl.

To assess the practicality of observation protocol used in this study, researcher had written the field notes during the observation on the interaction between scientist and students during the STSC-PPbl for 240 minutes at the university research laboratory. Researcher played his role as a teacher and participant observer in observation fieldnote-taking process. Researcher immersed himself into the collaboration session and recorded all the events happened on interaction between scientist and students. In accordance with the preliminary study of this data collection technique, there are few suggestions needed to be given attention to improve the acceptability of observation protocol:

a) Prioritize the descriptive observation note-taking first, followed by reflective observation note-taking first. As researcher himself serves as the participant observer in this study, it is always difficult to note down all the events happened during the interaction, thus always keep in minds the research objectives/questions in this study and record the significant events.
b) Always re-read the observation field notes taken and write the down the additional reflective field notes if any.

c) Prioritize the notetaking of conversations and behaviors of participants rather than description or summary of the conversation of behaviors of participants to avoid preconception that result in bias.

d) The observation notes collected at the initial stage was reviewed by a qualitative researcher who has science education research practice of ten years to ensure the correctness of participant observation notetaking strategies.

Figure 3.7 shows the design of this study.

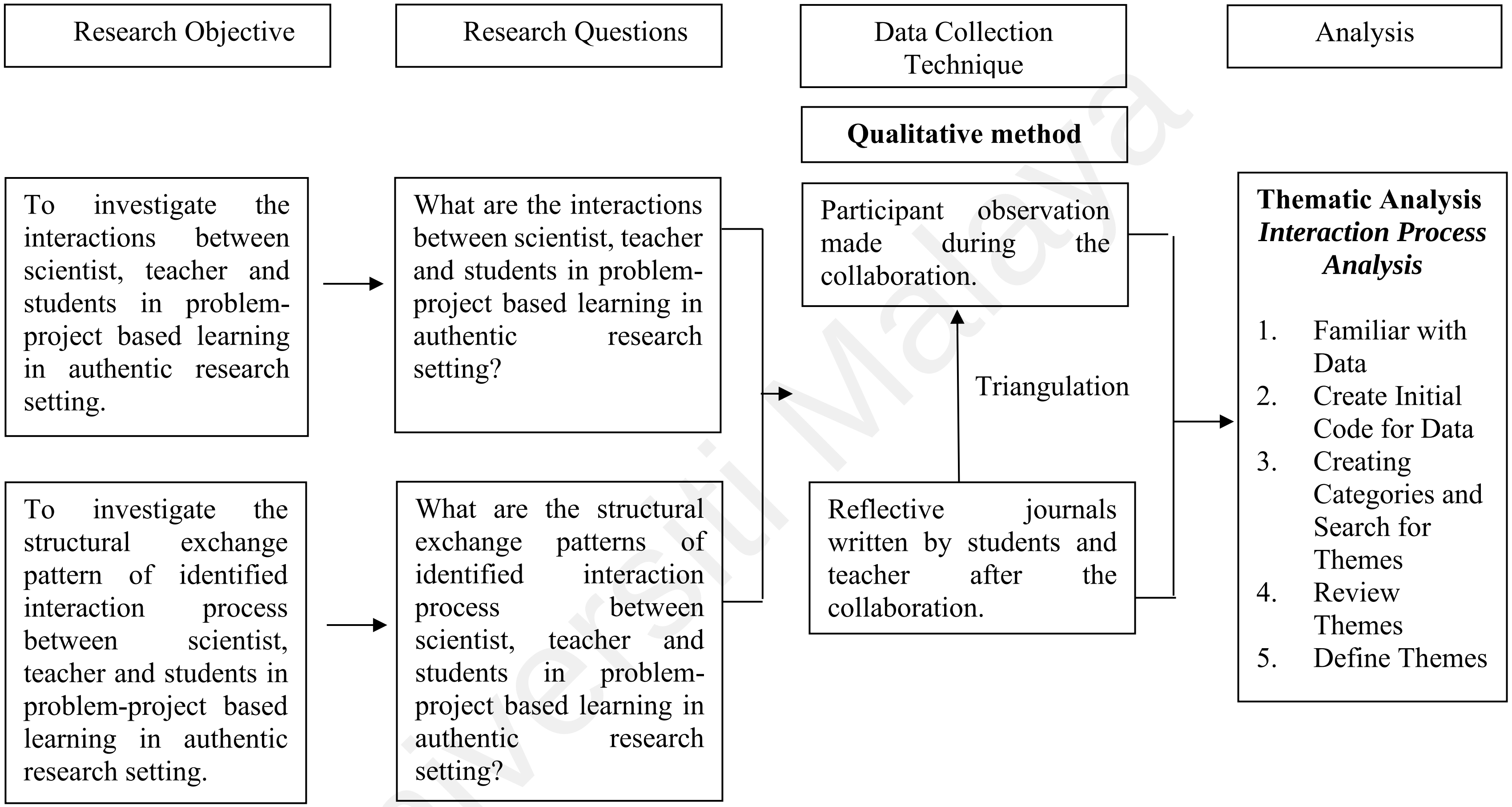

Figure 3.7 Design of this study

3.7 Data Analysis

Data analysis is central to credible qualitative research. Researcher employed integrated data analysis techniques to ‘visualize’ the interaction pattern which contribute to the comprehensive understanding on nature of STSC-PPbl . To answer the research questions, researcher employed interaction process analysis (IPA) (Bales, 1949) and structural exchange pattern analysis (SEP) (Fahy, 2001) picture the interaction process. Qualitative data from participant observation notes triangulated by reflective journals of students were analyzed by using both the Atlas.ti 8 (Scientific Software Development Gmbh Berlin, Germany) and manual coding. There are three stages of analysis in this section: preparing and organisation of data units, macro-level analysis and micro-level analysis as discussed below.

3.7.1 Preparing and Organization of Data Units

The first stage involved organizing the data in terms of types of activity and description of activity. This was done by coding the participant observation fieldnotes to identify the data units based on the types and description of activity. This process is illustrated in Table 3.6

Table 3.6 Data units prepared from observation field notes based on types of activities in this study

Date	Types of Activity
11, 13, 19 June 2018	Activity 1 Preparation of hot spring algae sample
11-14, 19 June 2018	Activity 2: Ethanolic extraction of hot spring algae
19 June 2018	Activity 3: Aqueous extraction of hot spring algae
29 June 2018	Activity 4: Antioxidant capacity study of hot spring algae

3.7.2 Familiarizing with the data

First and foremost, the organized data units were repeatedly read and re-read to note down the initial codes. It was crucial to familiarize with all the aspects of data. The process of preparation of the data layout and reading the data were time consuming, yet it is a good way to start familiarizing with the data (Riessman, 1993). It is important for the researcher to immerse into the data to the extent that researcher is familiar with the depth and breadth of content (Braun, Clarke & Terry, 2014; Erlingsson & Brysiewicz,2017). Thus, the collected data was read through at least three to five times before the coding process as the ideas and identification of possible patterns was shaped. The time spent in transcription and translation was not wasted, as it informed the early stages of analysis and developed more comprehension of the data.

3.7.3 Macro-level Analysis

The second stage of analysis have been adapted from Brown and Spang's (2008) analytical procedures involving events built based on the data units in stage one that organizes detailed participant observation field notes as shown in Table 3.6. Events are the efforts made by researcher to 'break up' the activity into smaller parts for the ease of investigation as supported by Bales (1950). Qualitative coding would be assigned to each involved participant based on the events mapped and mode of collaboration (bipartite or tripartite) would be identified as discussed below.

3.7.4 Generating Initial Codes

The generation of initial codes was in line with Boyatzis (1998), Miles and Huberman (1994) and Tuckett (2005) who are experts in thematic analysis. In this study, the process of coding was part of the analysis as the collection of data was organized into meaningful groups. These codes identified the features of data that appeared to be interesting and referred to the most basic segment, element of the raw data that can be assessed in a meaningful way regarding the phenomenon.

In this study, researcher used the open coding process. Before the coding process began, researcher read the definitions of categories of IPA (Bales, 1950, p. 177-198) to create theoretical understanding and "sense" of coding the participant observation notes. As the training for researcher himself, researcher coded some observation notes from other study to familiarize himself with the definitions of categories of IPA.

The coded data differed from the units of analysis or categories and themes which has a broader definition. The emerged codes were data driven and supported by theories of situated cognition theory and Vygotsky's social constructivism. The coding process was carried out using the Microsoft Excel for ease in organization of data. The coding process in this study was also in line with Given (2008) because it was best to keep an open mind and look for concepts and ideas directly correlate to the research objectives.

Since the coding was carried out using Microsoft Excel, the data layout was first prepared using Microsoft Word. The data was read word by word, line by line to get the first impression of the data layout. or considered as the "first thought" came across the minds when researcher read the data segments (Erlingsson & Brysiewicz,2017). Then, researcher got the first impression or picture on the idea for each of the data segments.

Then, the data were coded using open coding method. During the open coding, reading through the documents and highlighting the key words and phrases were the first run at the coding and conceptualizing the data. This was then followed by specifying rigorous emerging codes based on the key words or phrases highlighted during open coding as shown in Table 3.7.

After the open coding, some patterns that started to form were recognized because the open coding's primary goal was to find these patterns as documented in the data. It was time to refine, synthesize and explain the larger segments of research data. The coding process and the data were reviewed as they were grouped together. Subsequently, the codes were further compressed.

One of the limitations addressed on coding and categorizations of IPA is where understanding of a communication category starts out incorrect, the coding process will probably continue to be incorrect (Gorse & Emmit, 2005). To eliminate this limitation, researcher took "immersion and distancing" approach for three times (Vaismoradi, Jones, Turunen & Snelgrove, 2016). First, the focus reading method helped researcher to maintain closeness to the data and kept checking the preconceptions by constantly reviewing and comparing the previous findings of codes and data. The codes were recoded to better fit the data, new categories and new concepts or ideas. Secondly, researcher distanced himself from data for a period and/or reading the analysis from an "outsider perspective". Recoding process could also be done after the distancing to improve the accuracy of coding process.

The example of coding process is discussed as follow:

Sample of Observation Field Notes
(1 Interaction Event)

Students were collecting the algae from the bottom of the hot spring. *Teacher gave instruction to use the tools to obtain and collect the algae.* The algae were collected into a clean container and excess water was removed.

Parties Involved

TEACHER **STUDENTS**

TEACHER	STUDENTS
Extracted sentence: Teacher **gave instruction** to use the tools to obtain and **collect the algae**. In-vivo code: collect the algae ↓ Open code: Gave instruction	Extracted sentence: Students were **collecting the algae** from the bottom of the hot spring. In-vivo code: collecting the algae ↓ Open code: Follow instruction

Interaction
(Reciprocal Action)

By referring to one of the interaction events in the observation fieldnotes, the sentences were extracted if there was the interaction (or reciprocal actions) took place in accordance with the parties of participants (in this case, teacher and students). Then, for each participant, the in-vivo code was identified from the extracted sentence and the open code was assigned to the in-vivo code identified guided by answering the research questions in this study. For example, the in-vivo code identified for both parties of teacher and students is ‘collect(ing) the algae’. The open code of ‘gave instruction’ was assigned to teacher while ‘follow instruction’ was assigned to students for this action. As such, for the same action of ‘collect(ing) the algae’, the reciprocal action (interaction) between students could be elicited through the coding process.

The analytical method in this stage can show the sequence of event of single activity which clearly showed the contents and patterns of STS interaction emerged during the single activity (Table 3.7).

Table 3.7

Part of macro-level analysis in observation field notes

			SCIENTIST	TEACHER	STUDENTS
No.	Date	Event	Role/Action/Reaction	Role/Action/Reaction	Role/Action/Reaction
1	11/06/2018	Students were collecting the algae from the bottom of the hot spring. Teacher gave instruction to use the tools to obtain and collect the algae. The algae were collected into a clean container and excess water was removed.	-	Teacher gave instruction to students	Students followed the instruction from teacher

			Open Code			Mode of Collaboration
No.	Date	Event	Scientist	Teacher	Student	
1	11/06/2018	Students were collecting the algae from the bottom of the hot spring. Teacher gave instruction to use the tools to obtain and collect the algae. The algae were collected into a clean container and excess water was removed.	-	gave instruction	Follow instruction	Teacher-students

3.7.5 Micro-level Analysis

The interaction data were analyzed using two approaches in this study: (1) interactional elements by using interaction process analysis (IPA) based on Bales (1949) to analyze the content of interaction and (2) structural exchange patterns (SEP) using Transcript Analysis Tool (TAT) adapted from Fahy (2001) to picture the STS interaction pattern through quantification of qualitative codes generated from IPA. IPA (Bales, 1949) is a method used to categorize social interaction based on analysis areas among the members of small face-to-face group.

Table 3.8 shows the analysis areas of IPA used to analyze the participant observation fieldnotes adapted from Bales (1949). There are two analysis areas proposed in this analytical framework: neutral task areas (active or passive tasks) and socioemotional area (positive or negative). This framework serves as the initial guide for researcher to analyze the interaction process, yet researcher remains open in minds to let other possible analysis areas or themes to emerge during the analysis.

The relationships and definitions of each subareas in IPA used the perspective of 'problem-solving' as proposed by Bales (1950) to present the relationship between the interaction functions of scientist, teacher, and students during STSC-PPbl in this study. This perspective states that two or more people will interact with each other to solve a problem that raised by one of them. There are two types of characters involved in a function: 'active' task and 'passive' task in neutral task areas or 'positive' or 'negative' socioemotional areas. For instance, when the function of the role executes, the active task would exert the effect of function on the passive task.

Table 3.8

Six Interlocking Relationships (Active and Passive) and definitions for each subarea in Interaction Process Analysis

Neutral Task Area	Active Task	Example of Labels	Passive Task	Examples of Labels
Orientation	Gives orientation *Any act that reports factual observations or experiences*	Information, repeats, clarifies, confirms	Asks for orientation *Any act that requests factual observations or experiences*	Information, repetition, confirmation
Evaluation	Gives opinion *Any act that advances a belief or value that is relevant to the task*	Evaluation, analysis, expresses feeling, wish	Asks for opinions *Any act that requires a belief or value that is relevant to the task*	Evaluation, analysis, expression of feeling
Control	Gives suggestion *Any act that offers direction/action for how to engage the task with maximum amount of guidance and supervised condition*	Direction, implying autonomy for other	Asks for suggestions *Any act that requests direction/action for how to engage the task with maximum amount of guidance and supervised condition*	Direction, possible ways of solution
Independency (Theme)	Take initiative *Any act that shows completion and progress of a task and think actively with minimum or no assistance and supervised condition*	Independent task execution, active thinking, improved practice, progressing works	-	
Socioemotional Area	**Positive role**		**Negative Role**	
Decision	Agrees: *Any act that shows acceptance of what another person has said*	Passive acceptance, understand, complies	Disagrees *Any act that shows rejection of what another person has said*	Passive rejection, formality, withholds help

Table 3.8 (Continue)

Socioemotional Area	Positive role		Negative Role	
Tension management	Shows tension release: *Any act that reduces the anxiety that a person or group may be experiencing*	Jokes, laughs, shows satisfaction	Shows tension *Any act that indicates that a person is experiencing anxiety*	Asks for help, withdraws out of field
Integration	Shows solidarity: *Any act that shows positive feelings toward another person*	Raises other's status, gives help, reward	Shows antagonism *Any act that shows negative feelings toward another person*	Deflates other's status, defends or asserts self

Table 3.9 shows the example of TAT for SEP for STSC-PPbl interaction in this study. The TAT was constructed by first describing the interaction into a shorter sentence(s) with high closeness to the data from participant observation notes. Then, the codes were assigned to each description and the IPA label were assigned according to the codes assigned as guided by Table 3.8. Based on the IPA label, the category of interlocking subarea was assigned to the IPA label as guided by Table 3.8. Then, in accordance to the description of interaction, the label of active or passive (for neutral task area) and positive or negative (for socioemotional area) was assigned with reference to the role of participant (in this case, scientist). All the codes and labels given to the description of interactions would be used for quantification for calculations of SEP. This process was assisted by Atlas.ti 8 software (Refer Appendix D).

Table 3.9

Example of TAT in micro-level analysis of IPA of STSC-PPbl interaction in this study

Number of event	Description of interaction (SCIENTIST)	Code	IPA Label	Subarea	Active/Passive Positive/ Negative
2	Scientist gave instruction to students to wear PPE.	Gave instruction	Gives instruction	Control	Active
3	Scientist be friendly to students. Scientist calm students	Show friendliness	Shows solidarity	Integration	Positive
4	Scientist provided solutions to students	Gave solution	Gives suggestion	Control	Active
6	Scientist gave instruction to students	Gave instruction	Gives orientation	Control	Active
7	Scientist listened to teacher's suggestion	Listen to suggestion	Asks for suggestion	Control	Passive
14	Scientist gave instruction to students	Gave instruction	Gives orientation	Control	Active

To make the process of sequential analysis clearer, with reference to Event 2 of Table 3.9, the description of interaction of 'Scientist gave instruction to students to wear PPE' is generated based on in-vivo code and open code of 'gave instruction' assigned in stage 2 which is strictly adhere to the observation fieldnotes. With the guidance of Table 3.8, the open code of 'gave instruction' was labelled as 'gives instruction' based on description of subarea in IPA. The label of 'gives instruction' was further labelled as 'Control' to be categorized as one of the subareas in IPA in neutral task area and 'Active' as the direction for such interlocking reciprocal actions.

3.7.6 Structural Exchange Pattern Analysis (SEP)

SEP was done by quantification of interaction data to picture the apparent pattern and trend of interaction of STSC-PPbl in this study. SEP was done by adapting TAT developed by Fahy (2001) as shown in Table 3.9 by quantifying the qualitative codes generated in IPA. Besides that, the interaction pattern identified allowed researcher to understand who contributed throughout, who interjected periodically, who appeared to dominate the collaboration and which members were reluctant to communicate (Gorse & Emmit, 2005). The summary of categories of SEP is shown in Table 3.10

Table 3.10

Structural exchange pattern analysis adapted from TAT (Fahy, 2001) used in this study

Category	Description
Intensity of Interaction Functions (Neutral Task Areas or Socioemotional Areas)	The percentage of interaction functions played by each participant in this study
Density of Interaction	Ratio of the actual number of connections observed to the potential number of possible connections
Intensity of Modes of Collaboration	The percentage of modes of collaboration as calculated in this study

Table 3.10 (continue)

Category	Description
Active to Passive Neutral Task Ratio	Ratio of active or passive neutral tasks functions played by each participant in interaction
Positive to Negative Socioemotional Task Ratio	Ratio of positive or negative socioemotional functions played by each participant in interaction
Independent Task Ratio	Ratio of task carried out by students with little or no moderation from expert with reference to neutral task area functions

Intensity of Interaction Functions (Neutral Task Areas or Socioemotional Areas)

Intensity of interaction functions represents the frequency of interaction functions, either neutral task or socioemotional areas, played by participants as identified in participant observation notes during STSC-PPbl in this study. It is calculated by summing up the labels assigned at micro-level analysis as shown in Table 3.9.

For neutral task areas, the labels assigned that considered were *active* and *passive*. The intensity of interaction functions of each participant was represented in percentage by using the formula below:

$$\frac{The\ number(s)\ of\ active\ or\ passive\ labels\ in\ each\ neutral\ tasks\ function}{Observed\ number(s) of\ \ active\ or\ passive\ labels\ in\ each\ neutral\ tasks\ function}\ X\ 100\%$$

(Eq. 3.1)

For socioemotional areas, the labels assigned that considered were *positive* and *negative*. The intensity of interaction functions of each participant was represented in percentage by using the formula below:

$$\frac{The\ number(s)\ of\ positive\ or\ negative\ \ labels\ in\ each\ socioemotional\ function}{Observed\ number(s)\ of\ positive\ or\ negative\ \ labels\ in\ each\ socioemotional\ function}\ X\ 100\%$$

(Eq. 3.2)

Density of interaction

Density is the “ratio of the actual number of connections observed to the potential number of possible connections” (Fahy, 2001). The density of interaction was calculated based on the formula below:

Density = 2a / N(N-1) (Eq 3.3)

where *a* is the number of observed interactions and *N* is the total number of participants. The measurement of density of interaction suggested how connected individuals are to others in a group, and the higher the degree of connection, the higher the density of interaction. Fahy (2001) suggested that the density of interaction shall be equal or more than one. The value of density of interaction calculates shall be more than 1 to show that the satisfactory level of degree of connection in an interaction study (Fahy, 2001).

In this study, the density of interactions reflected ratio of the total number of events derived from all the activities from the participant observation notes in this study, which can refer from the column of “No.” as shown in Table 3.7. Researcher conceptualized density of interaction as how meticulous the researcher in scrutinizing and broken the activity into “smaller parts” of events to generate sufficient examined interaction data in this study.

Intensity of Mode of Collaboration

Intensity of interaction was calculated through summing up the number of labels of mode of collaboration as identified in Table 3.7 and the percentage of each mode of collaboration was calculated using the formula below:

$$\frac{The\ number(s)\ of\ \ labels\ of\ \ a\ mode\ of\ collaboration}{Observed\ number(s)\ of\ \ labels\ of\ all\ the\ modes\ of\ collaboration}\ X\ 100\%$$

(Eq. 3.4)

Active to Passive Neutral Task Ratio

The active to passive neutral task ratio a represents the degree of involvement of participants in interaction functions of neutral task areas in this study. This ratio was calculated by using the formula below:

$$\frac{The\ number(s)\ of\ active\ \ labels\ in\ \ neutral\ tasks\ functions}{Observed\ number(s)\ of\ passive\ labels\ in\ neutral\ tasks\ functions}$$

(Eq. 3.5)

Positive to Negative Socioemotional Task Ratio

The positive to negative socioemotional task ratio a represents the degree of involvement of participants in interaction functions of socioemotional areas in this study. This ratio was calculated by using the formula below:

$$\frac{The\ number(s)\ of\ positive\ \ labels\ in\ \ socioemotional\ functions}{Observed\ number(s)\ of\ negative\ labels\ in\ socioemotional\ functions}$$

(Eq. 3.6)

Independent Task Ratio

The independent task ratio represents the degree of independency of students in interaction functions of neutral task areas in this study. This ratio was calculated by using the formula below:

$$\frac{The\ number(s)\ of\ indepdendent\ \ labels\ in\ \ neutral\ task\ area\ functions}{Observed\ number(s)\ of\ labels\ in\ neutral\ task\ areas\ functions}$$

(Eq. 3.7)

During the quantification of codes and labels, researcher also needed to check whether there was any overlapped quantification, i.e. the codes that counted twice for the calculation of intensity of interaction functions. Figure 3.8 shows the analytic procedure in this study.

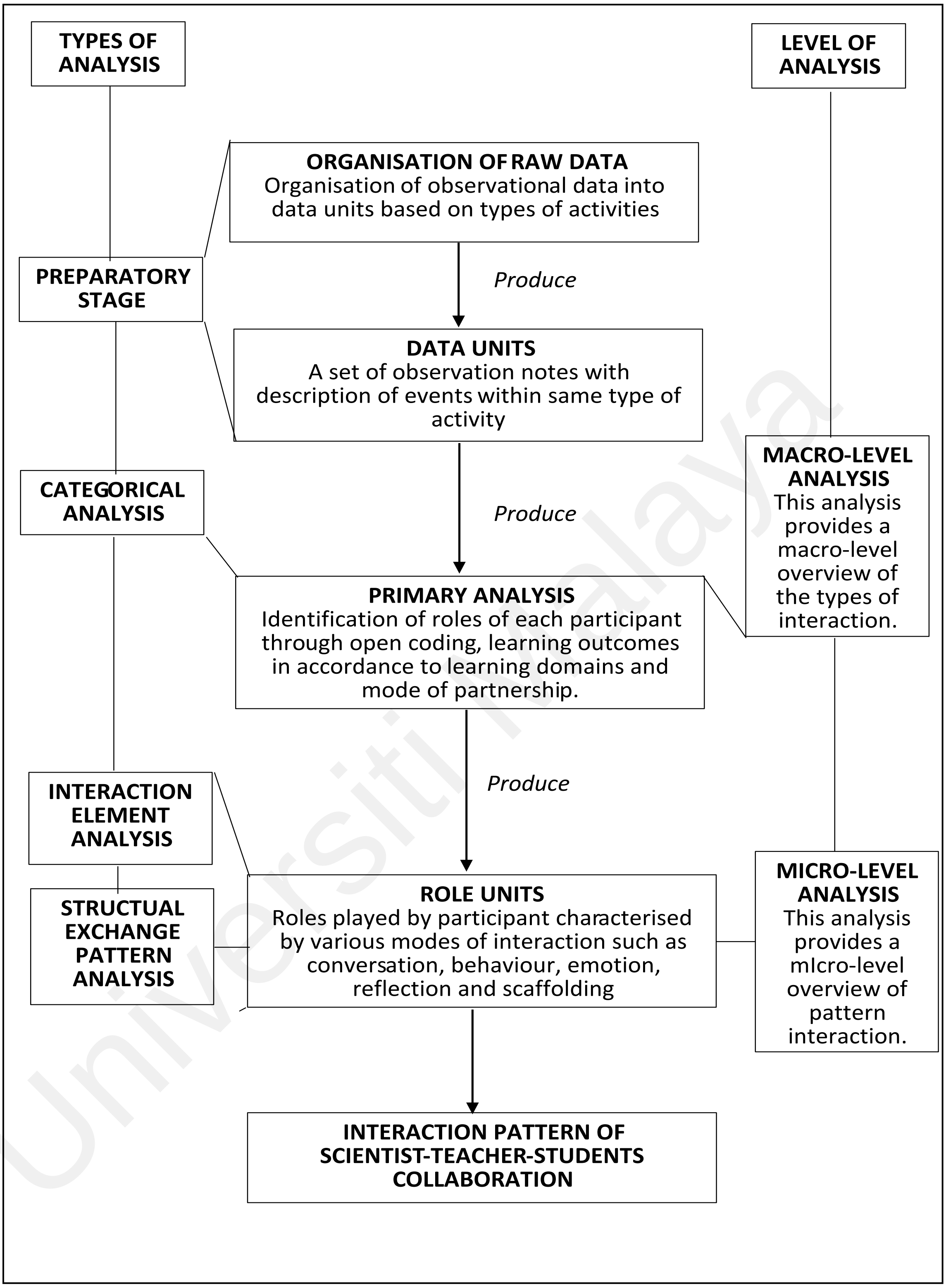

Figure 3.8 Analytic procedure of research questions (Bales, 1949; Brown and Spang, 2008; Fahy, 2001; Jaipal, 2009, 2010)

3.8 Procedures of Actual Study

The investigation of STSC-PPbl in authentic research setting employed several qualitative methods of data collection including participant observation notes during collaboration session and reflective journals written by students. The study could be conducted during normal classroom lessons, after schooling periods, mid-semester, or semester break.

3.8.1 Preparation and design of STSC-PPbl

The preparation of STSC-PPbl was time-consuming and challenging. It took around five months to complete as shown in Table 3.11.

Table 3.11

Timeline for Preparation of problem-project based learning in this study (bipartite collaboration)

Time/Year	Activity	Participants
Jan – Mac 2018	- Crafting problem and identifying topic of PPbl	- Teacher and students
Mac- May 2018	- Infusion of basic knowledge as required by PPbl - Seeking potential collaborator	- Teacher and students
April – May 2018	- Design the PPbl based on the problem and topic chosen - Fostering official collaboration between school and research institute	- Scientist and teacher
June 2018	- Visit to laboratory and final discussion with scientist	- Scientist and teacher

The researcher himself planned and carried out the activities with scientist or students during the preparatory phase in bipartite mode. The activities involved teacher and students include crafting problem and identifying topic, infusion of basic knowledge of PPbl and seeking potential collaborator; meanwhile activities involved scientist and teacher the design the PPbl based on the problem and topic chosen and fostering official collaboration between school and research institute. There was no fixed date and time to complete each activity and it followed the progress of the study.

3.8.2 Qualitative data collections during and after the collaboration

The outlines of the ways to collect qualitative data and the practical considerations that researchers need to be considered were guided by the progress of the problem-project based learning in this study. Table 3.12 shows the timeline for activity and data collection while Table 3.13 shows methods and purpose of methods utilized in the present study.

Table 3.12

Timeline for Activity and Data Collection in this study (tripartite collaboration)

Time/Year	Activity	Research Process / Data Collection
Jan – May 2018	Fostering collaboration with research institute and preparation of STSC-PPbl	- Proposal writing
June 2018	Interaction between scientist, teacher and students in STSC-PPbl	- Participant observation field notes - Reflective journals written by students after the collaboration
November 2018	Attending conference	- Writing paper and presentation
May - Sept 2019	Reflection on roles of teacher in collaboration (perception)	- Reflective journals written by teachers based on observation field notes

Table 3.13

Purpose and Method Utilised in this Present Study

Method	Purpose
Data collected during the collaboration	
Participant observations: note taking during the collaboration between scientist, teacher, and students in PPbl in a research institute.	✧ Collected over six days in three weeks in this present study ✧ Researcher would like to experience the whole collaboration session and gain some insights through self-reflection and observations made on scientist's and students' participations ✧ To recall as much information as possible, some photographs were taken. ✧ Data was validated by participant of this study.
Data collected during or after the collaboration	
Reflective journals from students	✧ Students reflected on the process of collaboration and write down their experience and feeling, as well as anything related about their thoughts pertaining the collaboration. ✧ Data was validated by participant of this study.
Data collected after the collaboration	
Reflective journals from researcher	✧ Researcher reflected on the process of collaboration and write down his experience and feeling, as well as anything related about their thoughts pertaining the collaboration.

There were generally two types of qualitative data collected according to phases: (1) data collected during the collaboration (participant observation notes); (2) data collected during or after the collaboration (reflective journals of students).

According to Tessier (2012), fieldnotes and reflective journals should be used together to enhance the quality of data management in data collection. Fieldnotes are important in capturing the behaviors and conversation during STSC. Thus, participant observation field notes are main sources of the qualitative data in this study. However, participant observation fieldnotes had some reliability issues because of their inability to "replay" the event (Tessier, 2012). Furthermore, as one of the participants in this study, researcher could not audiotape or videotape the whole process of collaboration to have good quality of engagements with all the participants. Therefore, the fieldnotes were cross-checked with the reflective journals collected from students to reduce the researcher's biasness.

3.9 Researcher's Bias and Assumptions

In this section, researcher would like state the bias and assumption that constituted this study. Researchers must be aware of these biases and enter the study with no misconceptions about not bringing in any subjectivities into the data collection process. Also, researcher possessed assumption to as a basis to design the PPbl as discussed below.

Engaging students to work with scientist and teacher in PPbl in authentic research setting is a new approach of pedagogical activity in most Malaysian schools. Hence, the researcher decided to take part by his own to experience and build in-depth exploration on the collaborative interaction with scientist, teacher and students in problem-project based learning in authentic research setting. The researcher is also novice in this study. With several years of participation in PBL and guiding secondary school advanced science projects, the researcher was well versed in the knowledge of project-based learning. However, it was not enough as practical experience is equally imporTomt in delivering the activities, confidently.

Researcher had conducted the advanced science PBL at high school level for two years, and one-year experience of STSC in doing advanced science project. Inviting scientist into the PBL is believed to engage students in science learning from a fresh perspective. To gain more insights in STSC-PPbl in this study, the researcher had participated the education expo as presenter to gain more knowledge and feedbacks from academicians and experts. The education expo was concurrently held with 2nd International Conference on STEM Education at central region of Malaysia.

Equipped with both research knowledge and prior experience, the researcher was confident in developing STSC-PPbl in this study.

3.10 Trustworthiness of the study

In this study, researcher intends to use some strategies to establish the credibility, and confirmability of the analyses and results. The credibility of data analysis of this study was established by using data triangulation method (both participant observation and reflective journals from students) and member check (Refer to Appendix J and K). This method will be used to improve the reliability and trustworthiness of this study.

Triangulation of different data sources was used to enhance the validity of this study. The coded data of observation field notes and reflective journals were cross validated, checked or triangulated to confirm the identified emerged theme. Types of data used such as observational field notes and reflective journals also helped to determine the validity if the findings. Data collection such as observation, reflective journals and audio-visual materials are triangulated in to interpret the descriptions and themes accurately.

In this study, researcher use also 'member check' to assure the internal validity of the study (Refer to Appendix I, J and K). Member check can also be referred to informant feedback or participant validation. Member checking was done on all the data collected in this study, which were observation field notes and reflective journals written by students. Member checking done by scientist was audiotaped, the feedback was recorded, and the participant validation form was signed as evidence.

Lastly, the confirmability of findings in this study will be established by reflecting on and articulating the limitations of the research, which was explained in Chapter 1. Also, researcher established research audit trail to assure findings in this study were in accordance with responses from scientist, teacher, and students instead of researcher's own preconceptions. Researcher also described the process of data collection and analysis in transparent manner by revealing examples of coding process, descriptions of how researcher worked from individual codes to theme, and rationale for what code were clustered together to form the basis of a theme.

3.11 Summary

This chapter discussed the research designs, participants, data collection protocols, procedures, and ways of interpreting the findings. The qualitative data collected from observation fieldnotes and reflective journals written by students were analyzed using IPA, structural exchange pattern analysis and thematic analysis. Through this detailed direction for each part of the research process, the research questions were believed to be answered.

CHAPTER 4: FINDINGS

4.1 Introduction

There are two research questions to be answered in this interaction study: (1) What are the interactions between scientist, teacher and students in problem-project based learning in authentic research setting? and (2) What is the structural exchange pattern of interaction between scientist, teacher and students in problem-project based learning in authentic research setting? Researcher had collected data to answer the research questions through participant observation as primary data source and reflective journaling from students as secondary data source in this study.

The process of analyzing interactions of STSC-PPbl in authentic research setting during STSC-PPbl was not easy as the data collected for several months was overwhelming and interaction process revealed certain extent of complexity and intricacies. Methodically, the analysis on interaction between STSC-PPbl comprises of Bales interaction process analysis (IPA) (1950) coupled with structural exchange pattern analysis (SEP) (Fahy, 2001). The findings were substantiated primarily by excerpts from participant observation notes triangulated by reflective journals from students which validated (member-checked) by both scientist and students in this study (Refer to Appendix I and J).

If qualitative research is to yield meaningful and useful results, it is important that the materials under scrutiny is analyzed in a methodical manner. The findings reflected how these three types of participants interacted with each other were indeed a daunting task. The struggle to portray the interaction during STSC-PPbl in authentic research setting was amplified as all the sources of data had to be carefully put together to solve the puzzle. The emerging themes, issues and visualized pattern were then identified. Some of the issues and meaning of interactions are not explicitly detected but have been implicitly stated.

This chapter is divided into four main sections. The first section is the findings on neutral task areas of STSC-PPbl to answer first subpart of first research question. The second section put all the findings of neutral task area elements of STSC-PPbl into deeper level of abstraction to depict the characteristics of roles of scientist, teacher and students pertaining to neutral task related areas functions. The third section is the findings on socioemotional areas of STSC-PPbl in order to answer another subpart of first research question. The fourth section presented structural exchange pattern of STSC-PPbl to answer the second research question. Then, the chapter summary is written to give brief description of this chapter.

4.2 Findings On Interaction Process Analysis (Ipa) Of Stsc-Ppbl

To answer the first research question in this study, researcher employed IPA as analysis framework adapted from Bales (1950) as shown in Figure 4.1. The aim of this section is to explore and describe the interactions during STSC-PPbl in depth to give researcher the rich understanding on the collaboration. Researcher reports the interaction as functions, i.e. duty of each participants in thematic manner as prescribed by Bales (1950) by using detailed data excerpts (Wilkinson, 1988) to present the construction and co-construction of meaning(s) of interaction by participant(s) in this study. The presentation of findings in this section follows the two analysis areas of IPA (Bales, 1950) namely, neutral task areas and socioemotional areas which consist of six subareas (orientation, control, evaluation, tension management, decision, integration) and an emerging theme (independency) was also discussed so that other interactions might not be overlooked (Figure 4.2).

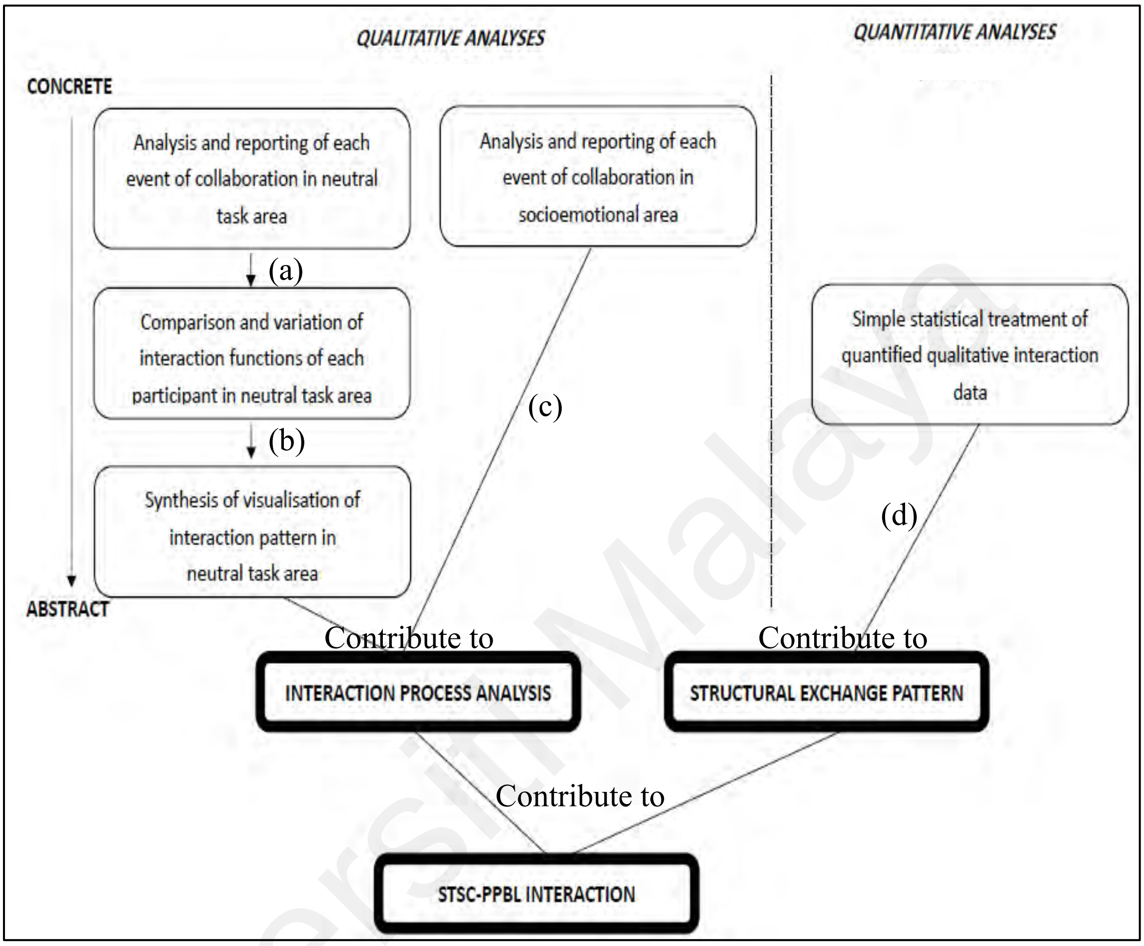

Figure 4.1 The outline of process of analysis and the presentation of findings in this study

Based on Figure 4.1, step (a) to (b) refer to qualitative analyses of interactions in neutral task area. The interaction functions of participants in neutral tasks of each event of collaboration were analysed using three-stage analytical procedure as discussed (Refer to Chapter 3: Data Analysis). After looking at comparison and variation of interaction functions, visualization of interaction pattern was synthesized to gain general understanding about the interaction pattern in neutral task area of participants in this study.

Step (c) refers to qualitative analyses of interactions in socioemotional task area. The interaction functions of participants in socioemotional areas of each event of collaboration were analysed using three-stage analytical procedure as discussed (Refer to Chapter 3: Data Analysis). However, visualization was not done for findings of socioemotional area because researcher found that socioemotional acts could vary due to personal characters of participants.

Step (d) requires researcher to present the structural exchange pattern of STSC which is quantification of overwhelming qualitative data of interaction to give the overview on the pattern of interaction contributed by each participant in this collaboration setting from simple statistical perspective. In overall, the analyses produced step (a) to (d) constitutes the description and picturization of interaction pattern in STSC-PPbl in this study.

4.2.1 Elements in Interaction Process Analysis of STSC-PPbl

Interaction process plays an important role for successful learning in STSC-PPbl. Thus, the findings of this section intend to provide insights of STSC-PPbl interaction in this study by answering the first research question based on IPA model shown in Figure 4.2

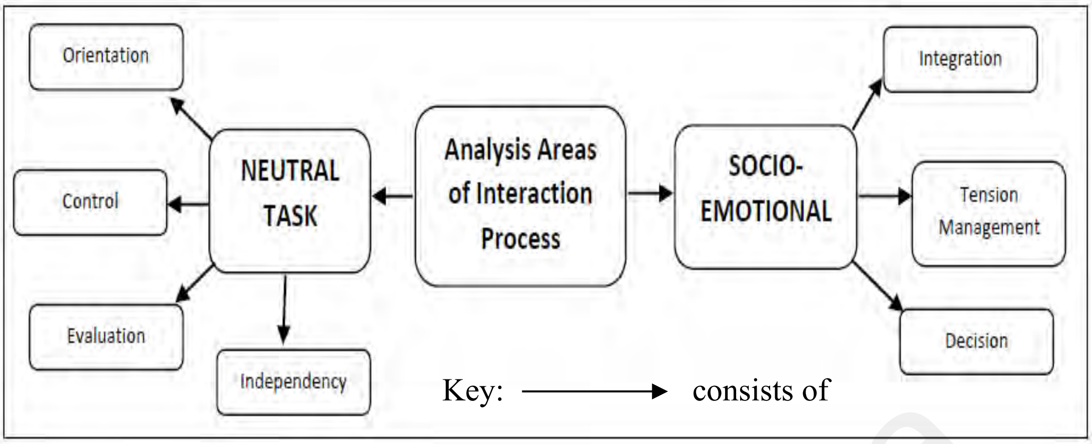

Figure 4.2 Analysis areas and subareas of IPA in this study
(Adapted from Bales, 1950)

Figure 4.2 shows the analysis areas and subareas of IPA in this study. There are two areas of IPA in this study in exploring the interactions during STSC-PPbl: neutral tasks areas (active and passive) and both socioemotional areas (positive and negative). In neutral task areas, there were three subareas named *orientation, control* and *evaluation*, and one emerged theme of *independency* which is not previously stated in IPA themes. In socioemotional areas, there were three subareas named *integration, decision,* and *tension management.* All the analysis of participant observation notes and reflective journals were analyzed with reference to the definitions of the subareas as explained by Bales (1950, p. 177-196). Figure 4.3 and 4.4 shows the shows the overviews of findings in this study.

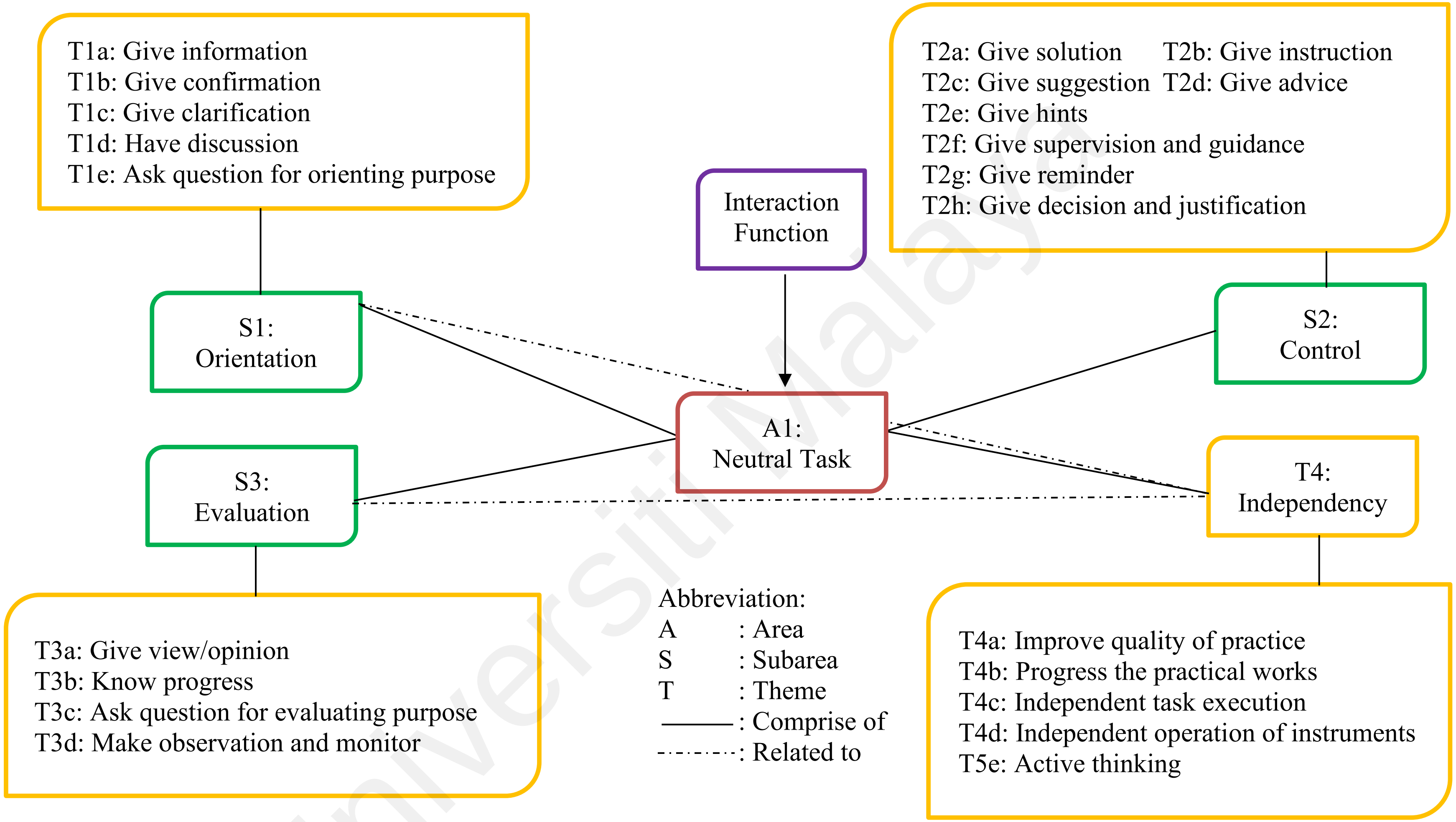

Figure 4.3 Overview of findings of neutral task area interaction functions

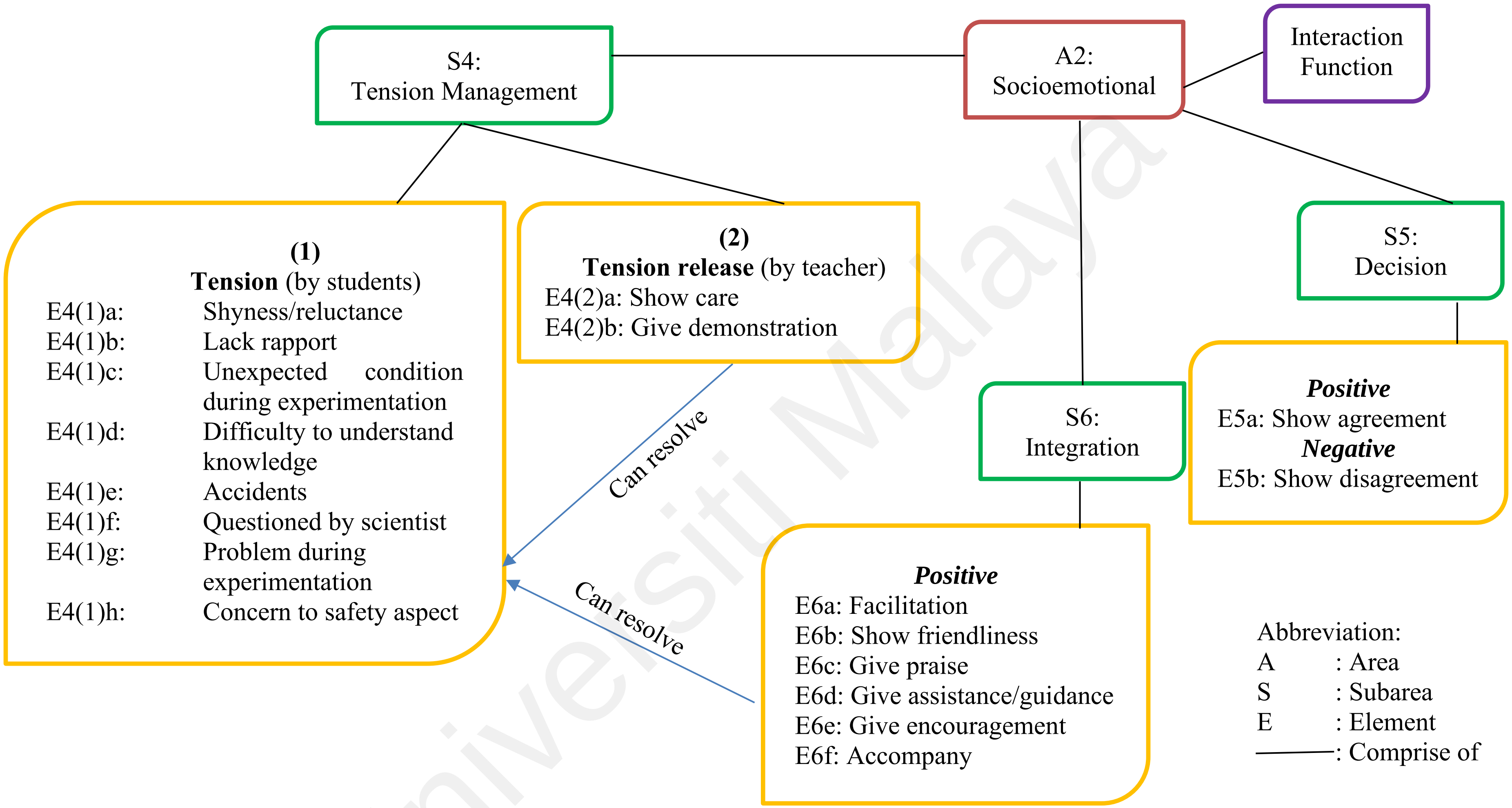

Figure 4.4 Overview of findings of socioemotional area interaction functions

4.2.2 Neutral Task Areas

There are three subareas underneath the neutral task named *orientation, control, evaluation* reflected in the functions of scientist, teacher, and students during interaction and one emerged theme *independency* only for the students during STSC-PPbl interaction. In each subarea, the findings were presented in term of the interaction function among participant in this study.

4.2.2.1 Orientation

Orientation refers to the action of orienting individuals to achieve the goals or execute the tasks during the interaction. It could be the process of activity or communication itself, the outer situations, and the motivational aspects as the object of cognition by scientist, teacher, and students in this study (Bales, 1950). There are five themes emerged under this area such as 'give confirmation', 'give clarification', 'give information', 'have discussion', and 'ask questions'.

(a) Give information

Researcher noticed the functions of scientist or teacher in providing information, which could be transformed to science knowledge gained by novice learners (students or teacher). The information provided could act as the source of knowledge to be learnt by students during the interaction in STSC-PPbl. (Note: However, the extent of information received by novice learners transform to knowledge is not investigated here). Researcher found that the ways of providing information could be in variety of manners such as demonstration, conversation, explanation etc. The ways of providing information could be viewed as pedagogical dimension to explore the way of teaching novice learner science during the process of STSC-PPbl.

In this context, students learnt science by first observing attentively and enacting more knowledgeable others' (MKO, scientist or teacher) demonstration, i.e. the practical exhibition and explanation given about the task execution that wished to be transferred to students. First, scientist gave demonstration to the students during the experimentation as shown in the fieldnotes below:

> *Sharon <u>demonstrated</u> the method to chopped and fold the filter papers to fit the small filter funnel.* (Observation, Activity 2, 12.06.2018, Event 6)
>
> *Sharon <u>demonstrated</u> how to use rotatory evaporator (rotavap) to evaporate all the ethanol to get the ethanolic extract of algae.* (Observation, Activity 2, 12.06.2018, Event 7)
>
> *Sharon first <u>demonstrated</u> the way to take out the samples and put them into small bottles for weighing, then she asked students to weigh the samples after watching the demonstration.* (Observation, Activity 4, 29.06.2018, Event 3)

Scientist provided the information by practical mean on the laboratory techniques such as *filtration (Event 6)* and *weighing (Event 3) techniques,* and operation of high-end instrument such as *rotatory evaporator* (rotavap). This showed that scientist was an authority in and cognizant of procedural knowledge in conducting scientific research. Students engaged in observational learning, i.e. used their eyes, ears and proximity to observe scientist' demonstration to acquire science procedural skills. The demonstration given by scientist could be somehow "factual" information to students based on Balesian IPA, however students grabbed the chance to "sense" the information before transforming it into execution as shown in Event 3 above.

Next, students also required teacher to provide demonstration to them as shown in the fieldnote below:

> *"Teacher, I would like to see you to do first," said Clark. Then, teacher operated the instrument for first time and Clark automatically assisted teacher to operate.* (Observation, Activity 2, 12.06.2018, Event 7)

Student might feel more secured after looking at teacher's demonstration, or he might lack confidence to operate the instrument independently for the first time. Student started involved himself in operation of instrument after teacher's demonstration, possibly signpost the increase in level of confidence and characteristic of *independence* (will be reported later), one of the indicators to grow independent learning in this study. This interaction reflected the concept of *scaffolding*, the gradual assistance provided by teacher (MKO) to student (novice) to develop instrumentation skills in this context. In this interaction, assistance was gradually removed, and degree of student's involvement rose during skill development.

Both scientist and teacher can team up to teach science to students or termed as "collaboration". Scientist asked teacher to demonstrate the laboratory technique to students as shown:

> *"Sharon asked Ben to demonstrate the handling techniques of micropipette to the students before letting them to do it. Ben demonstrated and explained the ways to handle the micropipette to students and students observed what teacher did."*
>
> (Observation, Activity 4, 29.06.2018, Event 6)

Scientist progressively involved teacher in giving demonstration and offered information orally (will be discussed later) to students (if teacher was able to demonstrate the sound laboratory technique).This interaction showed collaboration between scientist and teacher in science teaching, or it can be referred as "team teaching" in certain extent. Also, it can be said that teacher could deliver the information much clearer based on the existing understanding of students, which reflected the function of teacher as pedagogical expert that can transmit science knowledge to students.

Besides providing information by practical mean, scientist or teacher could also deliver information to students through oral explanation, which is a didactic approach. First, scientist offered oral explanation on the procedural skills as shown in the fieldnote below:

> *Sharon explained the process of reflux to students, starting from sample preparation and apparatus set-up.* (Observation, Activity 3, 19.06.2018, Event 1)
>
> *Scientist (Sharon) first explained to students about these three terms: "There are 3 types of controls: positive, negative and blank. Controls allow the user to have confidence that sample results are because of a set variable and not due to a random factor. Furthermore, controls can give an indication of signals which are not due to the target or analyte."*
> (Observation, Activity 4, 29.06.2018, Event 12)

Scientist offered explanation orally on the procedural knowledge such as "*reflux technique"* and the concept of "*controls*" in experiments to the students. Scientist would like to give students the general idea or picture about the procedure before the experimentation started. This interaction reflected the function of scientist as science knowledge expert in this context.

On the other hand, teacher also provided oral explanation to students about the procedural knowledge as shown:

"Teacher, why we need to do this?" asked Mark. Clark nodded too. Initially, they did not understand the purpose of control.
"This is just like an indicator to check the mass loss. We took little bit algae and keep measuring the mass loss based on this fraction of algae. The mass loss here could represent moisture content of the bulk of algae. Do you understand?" Ben tried to explain to make them understand the purpose of control.
(Observation, Activity 1, 11.06.2018, Event 14)

Thomas observed the fluctuation of the temperature of the chiller. They looked at the rotavap and started thinking about the function of rotatory evaporator. ... Teacher (Ben) then explained why this phenomenon occur and function of rotatory evaporator. (Observation, Activity 2, 14.06.2018, Event 17)

Teacher provided explanation based on the curiosity aroused by student when they asked questions. The curiosity can also be observed when students looked at the instruments and teacher could offer explanation based on such curiosity.

In contrast with the oral explanations which were much purposeful teaching in STSC-PPbl as reported above, sometimes students would have curiosity out of sudden (more spontaneous). The spontaneous function of scientist by providing explanation to students through interactive conversation could answer the inquiry of students as shown in the fieldnotes below:

"Madam, why we need to cover the bottles with parafilm?", said Mark.
"To avoid water enters the samples and contaminate them," answered Sharon.
(Observation, Activity 4, 29.06.2018, Event 7)

During the sonication process, Mark asked Sharon why they cannot use normal stirring process to homogenize the solutions.
"Sonication can homogenize the solution better as it generated strong waves to vibrate the bottles as compared to normal stirring process" answered Sharon. (Observation, Activity 4, 29.06.2018, Event 8)

"Madam, I just don't understand why we need to use reflux to obtain the aqueous extract of hot spring algae?" replied Thomas.

Sharon then tried to explain the working principle of reflux and its significance in reduce the loss of phytochemicals during the extraction process of hot spring algae. (Observation, Activity 3, 19.06.2018, Event 2)

In this event, student had inquiry on the reasons behind the choices of procedure for the experimentation in this study. This indicated students started thinking about the rationale of choice of procedure regarding experimentation. Scientist provided explanation to answer the inquiry of the student. Researcher noticed that another student rose the question and asked scientist:

"Madam, I don't understand why we need to reflux the mixture, rather than just soaking the hot spring algae in water just like ethanol extraction?" asked Mark.

"Boiling (heating) the mixture will extract the phytochemicals which is soluble in water." Replied Sharon.

"Then, why can't ethanolic extract use this method to extract the phytochemicals?" asked Mark.

"Actually, this is because the deficiency found in function of heating mantle which is not digital. Therefore, we could not adjust the reading of temperature. Furthermore, we can use another technique of extraction called Soxhlet extraction," explained Sharon and bring the students to the apparatus set-up. "Ooo…" Mark nodded.

(Observation, Activity 3, 19.06.2018, Event 3)

By looking into Event 2 and 3 as shown above, researcher found that different students had different 'cognition', in this case, prior knowledge or knowledge by default which might be due to different learning background and knowledge acquisition process. Both students were curious about the choice of using reflux technique to extract the phytochemicals, but their curiosities were aroused from different types of understanding. During the activity, they conducted two different extraction techniques: solvent extraction using cold soaking method and aqueous extraction using reflux technique to the hot spring algae in this project. Therefore, student in Event 3 presumed that the aqueous extraction technique would be similar with solvent extraction technique (…*soaking the hot spring algae in water just like ethanol extraction*). Therefore, this emphasized the importance of conversation between scientist and students during the interaction to resolve the doubts aroused by students with different knowledge by default. It appeared evident student in Event 2 just asked a question to make the understanding clear, while student in Event 3 asked a series of questions to gain understanding.

Besides that, researcher also noted that both scientist and teacher could work together in providing oral explanation to give information to students during the interaction. Firstly, in this fieldnote, scientist assumed a passive role (as presumed by Bales IPA) by asking teacher to give explanation to students as shown:

> *…, Sharon explained the working principles of readings the absorbance to study the antioxidant capacity.*
> *"Madam, what is the relationship between absorbance and antioxidant capacity?" asked Mark.*
> *"We need to look at the intensity of purple colour to study how much radicals have been scavenged by antioxidants. It is at 519 nm," answered Sharon.*
> *"Why we need to study the intensity of purple colour to know the antioxidant capacity" asked Mark.*
> *"Ben, could you please explain to your students about this?" said Sharon.*
> (Observation, Activity 4, 29.06.2018, Event 14)

Scientist first gave the explanation to reply students' question and teacher followed up by supplementing the explanation given by scientist. This sequence of explanations given by scientist followed by teacher could be viewed as one of the approaches in collaborative teaching. Scientist might believe that teacher could assist her to explain the information better to students. This also showed that both scientist and teacher had knowledge by default prior to this project.

Student seemed to gain understanding after listening to explanation made by both scientist and teacher as shown in the fieldnote below:

> *After listening to the explanation made by teacher (Ben) and professor (Sharon), I thus understand the polarity …* (Reflection, Thomas)

Besides that, student provided explanation on the structure and operation of instruments that learnt in science classroom as shown in the fieldnote below:

> *Ben encouraged students try to explain the principle of reflux based on what they learnt and understand in the chemistry classroom. Then, Clark offered him to do it.* (Observation, Activity 3, 19.06.2018, Event 4)

> *Clark has bravely explained the working concepts of reflux …* (Reflection, Mark)

Teacher promoted this interaction by encouraging students to explain what they understand about the instrument as they have learnt in in Chemistry subject. Then, student took initiative to give explanation in this event. This interaction expressed the science learning as a form of externalization of knowledge learnt by students. i.e. expressed their knowledge or understanding in the form of oral explanation and teacher could understand what they knew about the instrument simultaneously. Besides interacting with teacher and students during the explanation, student needed to interact with the 'context' of the project, which is instrument. This is in tandem with the situated cognition theory, i.e. by situating the student in the authentic research environment and student grabbed the chance to express his prior, existing understanding with the role of moderation played by teacher in this event.

(b) Give confirmation

Researcher noticed that confirmation and clarification (will be discussed later) need to be given by MKO to students or teacher (novice learners) during the process of PPbl in this study for various functional and inquiry purposes. The confirmation obtained and achieved for science learning could give assurance and increase the confidence in science learning during the task execution or improving understanding on procedural knowledge. Also, confirmation given by MKO can convert "inquiry" of learner to "gain" in cognition. However, confirmation, in relative to clarification, is only the action of ascertaining, without further providing any additional information to the receiver.

First, scientist gave confirmation on the answers or responses given by the students during questions and answer session as shown in the fieldnote:

> *Ben asked students why we need to chop the algae into smaller pieces before putting them into conical flask for ethanolic extraction.*
> *"Errr….." Mark felt awkward. Mark initially has no idea about that.*
> *Clark answered Ben's question: "to increase the surface area for complete extraction of phytochemicals".*
> *Soon, Sharon came and clarified* (corrected as confirmed) *the reason why Mark and Clark need to do so. "Yea, that's right.", replied Sharon.*
> (Observation, Activity 2, 11.06.2018, Event 2)

In this fieldnote, teacher evaluated students' understanding on the procedural knowledge which falls under *evaluation* category in IPA (will be reported later). While teacher was checking students' knowledge on the methodology of experimentation in this study, a student gave the response based on his prior knowledge. In this event, scientist ascertained the response given by students to confirm the correctness of knowledge. Confirmation given by scientist prior to students' responses could make students clear and certain about their response given to the teacher. The confirmation given by scientist also supported student's explanation, the quest of answering teacher's question based on what student believe in accordance with his prior knowledge.

The doubt(s) aroused when students were doing experiment. Scientist gave confirmation to students to resolve the doubt as shown the in the fieldnote below:

> *When we were doubting whether we could have done it wrongly, madam (Sharon) said that it should look like this, then we were ascertained about what we did was right.* (Reflection, Mark)

The unsureness of task execution steps during experimentation from students can be resolved by scientist's confirmation.

Scientist also gave confirmation followed by suggestion (will be reported in *control*) to students on the condition of the experiment as shown:

> *Sharon said it is enough to run the tests. If it is not enough, Sharon suggested to do sample and extraction again if necessary.*
> (Observation, Activity 2, 14.06.2018, Event 26)

Scientist confirmed the condition of the experiment with the phrase of "*enough to run the tests".* Then, scientist provided suggestion to students if the speculated condition was not happening which falls under the *control* function (will be reported later). This showed the "orientation-control" functions in sequential manner. This reflected the function of scientist as scientific methodological expert in monitoring and confirming the condition of experiment.

(c) Give clarification

Clarification is the action of making a statement or situation less confused and more comprehensible by individual. It appeared evident that confusion (as object of cognition) might be aroused during the process of inquiry. During the communication process, clarification involves checking listener's understanding, then offering back essential meaning to the listener to resolve any areas of confusion or misunderstanding. Rather than ascertaining like confirmation, clarification needs explanatory statements to increase the understanding besides sole confirmation.

The confusion aroused when novice learner(s) made observation during experimentation. In this case, teacher (as the novice learner) made observation and unsure about the identity of product formed. Scientist gave clarification to teacher during the experimentation as shown in the fieldnote below:

> *"Wow, the smell is like seaweed soup." asked Ben. "Is this really the aqueous extract of hot spring algae?"*
> *"Yea, this is the extract." replied Sharon.* [Confirmation]
> *"Why does it appear brown? Not green." asked Ben*
> *"Of course, different types of phytochemicals are extracted out" answered Sharon.* [Explanatory statement] (Observation, Activity 3, 19.06.2018, Event 5)

Apparently, teacher confused about observation he made on the extract obtained from the reflux. Although teacher possessed science knowledge, but he needed clarification from scientist to confirm the observation he made. Teacher soon expressed his doubt after the gaining confirmation by scientist about the observation he made, then scientist offered explanation to resolve teacher's question. This interaction was meaningful as the explanation offered teacher understanding from his confusion, reflecting the function of scientist as subject matter expert and teacher as novice learner in this case.

(d) <u>*Have discussion*</u>

Researcher also noted discussion as interactive teaching and learning strategy in transferring (delivery and reception) of information. The fieldnote below showed teacher had discussion with students to improve the quality of practices as shown:

> *They started <u>discussing</u> with Ben how to collect the fresh algae better.*
>
> (Observation, Activity 1, 11.06.2018, Event 10)

The discussion held between teacher and students gave more chances to students to express their thoughts to improve the quality of sampling practice, for instance. The topic of the discussion centered about *"how"* which might involve the exchange of ideas and reaching consensus on decision of sample collection between teacher and students Researcher claimed that the expression of thought by students could be a sign of achievement of *independency* (will be reported later) as they *"started"* the discussion with teacher.

(e) <u>*Ask question for orienting purpose*</u>

Researcher noted that questioning as interactive learning strategy to obtain information from MKO by novice learners in this study. This function was considered as active role from the perspective of problem-solving as taken by students based on definitions Balesian IPA categories (1950) perspective.

> *Mark asked why they need to tare before weighing. "This is because we want to set the weighing balance back to zero before weighing," Clark answered him.*
>
> (Observation, Activity 1, 11.06.2018, Event 13)

Questioning is one of the important learning strategies in improving one's understanding and gaining knowledge during the moment that stimulate one's thinking. Student asked the question to his peer at that instant to know the reason behind the task execution (for example, tare) in weighing samples. Besides that, students asked teacher questions in the quest of understanding as shown:

> *"Teacher, why we need to do this?" asked Mark. Clark nodded too. Initially, they did not understand the purpose of control.*
>
> (Observation, Activity 1, 11.06.2018, Event 14)

In summary, the data revealed various orientation functions of 'give confirmation', 'give clarification', 'give information', 'have discussion', and 'ask questions' during STSC-PPbl interactions imposed effects, either by active or passive, on the quest of understanding of participants during the task executions. It also intended to make participants to express the information to another for smooth task completion. It pictured the ways of ways and manners of information transferring among participants during science learning and teaching processes during STSC-PPbl.

4.2.2.2 Control

Control functions is giving suggestion, direction, and implying autonomy for other (Bales, 1950). They assume the process of cooperative action itself in its conative-instrumental aspect or the desired action of the other as the object of conative-instrumental effort that will be discussed below. In control functions, the highly supervised learning condition provided by scientist and teacher were given to students as discussed below.

(a) <u>Give instruction</u>

In this study, both scientist and teacher gave instruction for different functional purposes pertaining to smooth process of PPbl as well as assuring science learning by students. Giving instruction is considered “the desired action of the other as the object of conative-instrumental effort” (Bales, 1950). The science learning deliverables to students by scientist and teacher often adopted direct instruction pedagogical method. It means that scientist and/or teacher stood in front of students and presented the information to students for them to complete the tasks or enrich their understanding as the object of cognition of students.

Scientist gave instruction to guide the students to work on the research and experimentation for different purposes. First, for example, scientist gave instruction to students to wear personal protective equipment (PPE) as shown:

> *“Sharon asked the students to wear the lab coats, gloves and masks before doing the experiments.”* (Observation, Activity 1, 11.06.2018, Event 2)

> *Clark was helping me to weak face mask* (Reflection, Mark)

Researcher claimed that there was little or no use of PPE to conduct experiment in school science teaching laboratory.

> *Based on my experience as chemistry teacher, during the chemistry experiments lessons in school, students were not used to wear lab coats, gloves, and safety goggles. We just taught them some safety precautions about the experiment.*
>
> (Memo, Ben)

This situation clearly distinguished the culture of “authentic science” from “school science” in term of safety measures (PPE). The instruction given by scientist instilled fundamental safety awareness to be considered in research laboratory as compared to science teaching laboratory in school. Researcher observed that students automatically wore the PPE before entering the laboratory to do experiments with scientist after the first instruction given by scientist. This indicates that such habit had been successfully fostered within students upon the instruction of scientist at the beginning stage. The instruction of scientist serves as the process of communication between scientist and students as the object of cognition appeared in this interaction. This instruction intended to secure the attention of students to the necessity of wearing PPE as the one of the working cultures in the laboratory.

Scientist gave instruction also to assure attentive delivery of information to students during communication process. This fieldnote shows scientist gave instruction to students to note down the information that she delivered to do the experimentation as shown:

> *She (Sharon) noticed that students did not take note and instructed the students to take out the notebooks and record what she said.*
> (Observation, Activity 4, 29.06.2018, Event 1)

The intention of this instruction from scientist could be the assertion on the necessity of notetaking by students during the delivery of information. This might be due to scientist would like to make sure all the information could be delivered fully and being paid attention by students to conduct the experiment later in the research laboratory. The notetaking strategy that scientist would like students to do might reflect that students did receive all the information given by scientist.

Scientist gave instruction to students to direct them to be more independent in deciding and clarifying the methods of experimentation. Students might not be clear about some parts of methods of experimentation and they consulted scientist for solution or decision. Take, for example, this fieldnote passage describing the interaction between scientist and students:

> *Mark and Clark asked Sharon regarding the method of drying algae samples. Sharon asked students to look for drying temperatures based on literatures.*
>
> (Observation. Activity 1, 11.06.2018, Event 12)

Students were instructed to refer literature to further decide which temperature for drying the hot spring algae sample. This could be one of the strategies used by scientist to make students to be more independent rather than "spoon-fed" during the experimentation process. It was said to oppose the 'cookbook style' of science experiments in existing science syllabus that provide all the details of experiments and students just follow them exactly. Scientist did not provide the solution to the inquiry aroused by students, instead students needed to refer sources of information to decide the methods used. This illustrated scientist modelled her way to transfer the science learning to students by making them "explore and decide" rather than just merely providing solutions to them. Thus, students needed to read the past studies then make decision on the drying temperature. The process of communication between scientist and students as the object of cognition in this interaction.

In this study, students needed to work with scientist and teacher to complete a scientific investigation. Scientist, as MKO in this study, gave instruction to students to conduct the experiments as shown in the fieldnote below:

Clark and Mark were instructed by Sharon to collect little fresh algae samples and put into beaker to study the moisture loss in fresh samples to get the dry mass of samples (serve as control).

(Observation, Activity 1, 11.06.2018, Event 14)

Sharon instructed the students to weigh 1 mg of each sample.

(Observation, Activity 4, 29.06.2018, Event 2)

These showed that scientist was an authority in procedural knowledge in conducting experiments in research laboratory or in the field of study. The instruction delivered from scientist to students during experimentation could be viewed as process of transfer of skills and knowledge through direct instruction approach. Also, the instruction given by scientist could be viewed as verbal "scaffold" to help students to execute task and even improve their procedural skills and knowledge. Since teacher and students could do the experiment together as collaboration in the observation during the study, there is evidence from observation notes that scientist give instruction to both teacher and students for task execution during experimentation as shown:

Ben and Tom were asked to grind the dry algae samples to become powdered form. Sharon said that each phytochemical test required 5 grams of dry algae samples and there are 5 tests in total.

(Observation, Activity 1, 13.06.2018, Event 16)

In this event, teacher was considered as a 'novice learner' at certain extent and he needed to listen to the instruction from scientist to run or 'hands-on' the experiments. Also, teacher could be the "accompanier" for students during the process of experimentation by giving instruction to students to execute the task, which could be classified under the category of *integration* (will be reported later). The act of accompany by teacher could be viewed as showing solidarity or support, either technically or morally, to students when they were conducting experiments.

Besides that, teacher also gave instruction to students to execute the task as shown in the fieldnotes below:

> *Ben gave instruction* (to students) *to use the tools to obtain and collect the algae.*
>
> (Observation, Activity 1, 11.06.2018, Event 1)
>
> *Tom were instructed by Ben to resume the weighing process as done by their teammates yesterday.*
>
> (Observation, Activity 1, 11.06.2018, Event 15)

The instruction given by teacher to students might be due to assure students to complete the task (algae sample collection and resuming process/works) as described in the excerpts. This reflected the role of teacher in giving instruction to students was to assure students could maximize their engagements to the learning process in PPbl as instructed by scientist.

Based on the interaction functions discussed, science learning of students showed certain extent of instructionism in this study, which refers to the learning processes were characterized with MKO-controlled, skill-based and highly prescribed due to early planning by both scientist and teacher. However, the learning processes were still considered interactive as students were allowed to execute their interaction functions with their own thoughts.

(b) Give solution

Scientist needed to provide solution to students as novice learners to resolve problems encountered during the task execution or experimentation. First, scientist directly gave the solution to students to overcome the problems emerged during experimentation as shown in the fieldnote below:

"Wait yea… How to filter all the algae here?" Sharon was figuring out how to filter the samples by proposing some solutions to students.

Mark and Clark stood there and waiting for the instructions to filter the samples. Finally, Sharon <u>decided to use the sieve and tissue to remove the moisture in the algae.</u> She passed the sieve and tissue to Mark and Clark.

"Ooo… okay…" nodded Mark and Clark Then, Mark and Clark just followed Sharon's instruction to dry the algae using the sieve and tissue given.

(Observation, Activity 1, 11.06.2018, Event 4)

Based on the event above, scientist thought about and figured the way to run the filtration and directly provided the solution to students. This reflected the role of scientist took part actively as solution provider during the task execution and scientific practice expert as she has adequate knowledge to devise the solution to problem during experimentation. Meanwhile, researcher observed that students were just standing aside and waiting for the solution given by scientist. Students might had no idea about how to handle the filtration due to lack procedural knowledge, or they just merely relied on scientist's instruction and solution to proceed with the task execution.

By referring to the fieldnotes, students asked scientist about the solution to the problem during experimentation and task execution without given direct solution by scientist as shown below:

As the quantity of solvent needed is in small amount (1 ml – 5 ml), students asked Sharon and Ben how to measure the volume of the solvent. Sharon answered students "We use micropipettes to do that."

(Observation, Activity 4, 29.06.2018, Event 5)

Then, the cleaned algae were chopped into smaller pieces for ethanolic extraction process. "Madam, how to cut the algae?", asked Mark. Mark and Clark asked Sharon for methods to reduce the size of algae, finally they were *given the cutter to chop the algae samples. "Just use this cutter," replied Sharon and passed him a cutter.*

(Observation, Activity 2, 11.06.2018, Event 1)

As compared with the event (direct solution given by scientist) above, scientist did not tell students how to execute the task or experimentation. Students were just provided tools to solve the problems. This might be due to scientist expected students were able to execute the task. The difficulty of tasks varied, in these events, cutting the hot spring algae sample and transferring tiny amount of solvent. However, students still consulted scientist about the solution. Scientist still needed to give the solution to students due to inadequate practical or procedural knowledge possessed by students. There might be transfer of practical or procedural knowledge from scientist (who is in authentic science context) to students (who is in school science context) in these interactions.

Teacher worked together with scientist to provide solution to students as shown in the fieldnotes below:

They then tried to change the methods to ease the filtration by keep changing the filter papers and transferring the mixture. Sharon and Ben began to offer solutions to overcome this problem.

(Observation, Activity 3, 19.06.2018, Event 6)

This event illustrated the collaboration of scientist and teacher in providing solutions to students in overcoming the problems during experimentation. Researcher noted that students started to involve themselves actively in problem-solving during experimentation by *"changing the methods"* (Event 6, Activity 4) rather than just *"standing aside*" (Event 4, Activity 1), which might indicate the sign of *independency* in this interaction (will be reported later). In other words of saying, by looking at the transition period from Activity 1 to 4, students engaged in improvement of procedural knowledge as active problem solver, even though the nature of tasks were similar or varied in these two activities.

(c) Give suggestion

In this study, suggestion refers to an idea or plan put forward for consideration. Scientist provided suggestion to students based on the condition of experiment to progress as shown:

> *Sharon said that we need to collect more samples for drying for aqueous extraction. She suggested Mark and Clark to collect the samples again since there was still ample time to do the successive lab works.*
>
> (Observation, Activity 1, 11.06.2018, Event 8)

Students considered the suggestion provided by scientist by making use the spare time to continue the experimentation by doing sampling again. Then, students provided suggestion on their plan to teacher as shown:

> *Students started suggesting the time plan to the teachers regarding the second sampling of fresh algae. They started allocated the time for lunch, subsequent sampling and when would get back to the laboratory.*
>
> (Observation, Activity 1, 11.06.2018, Event 8)

Apparently, the suggestion (*collect more samples*) provided by scientist triggered the suggestion provided by students (*the time plan*) to teacher to assure the task completion as suggested by scientist. This reflected the function of scientist in assuring completion of project and students were the executors. This interaction gave students the chance to practice the time planning and allocation to assure the completion of laboratory works in the context of this study.

Besides that, scientist also offered suggestion for students to further the direction of project as shown in the fieldnote below:

Madam (Sharon) had suggested us to look at chlorophyll quantification. I thought it was very useful. (Reflection, Mark)

The "*chlorophyll quantification*" as suggested by scientist was not in the scope of PPbl in this study. Scientist made this suggestion because she observed the dark green colour of the ethanolic extract produced from hot spring algae wet sample. This suggestion could serve as the further scope of the project, either students can take and complete this scope if the time allocation is available or the expansion of study for next batch of PPbl. The suggestion made by scientist reflected her function as the science knowledge expert in this study, i.e. she had adequate knowledge to put forward this suggestion to students to further the scope of study that might lead to new contribution of the knowledge.

Students also provided suggestion to scientist to improve the method after experience the handling of laboratory techniques as shown:

Clark asked for two extra conical flasks to run the filtration simultaneously, which would make the works got finished faster.
(Observation, Activity 2, 12.06.2018, Event 6)

Then, student also suggested the further progress of experimentation to scientist after having experience and knowing the conditions of the experiments:

Sharon said it is enough to run the tests. If it is not enough, Sharon suggested to do sample and extraction again if necessary. Clark suggested that larger amounts of hot spring algae need to be sampled again.
(Observation, Activity 2, 14.06.2018, Event 21)

By looking these two events, students began to take control of process of experimentation in procedural improvements and progress planning, giving students more autonomy in research progress. This might indicate little epistemical involvement in authentic science learning, i.e. students have chance to model the PPbl process.

(d) Give advices

In this study, advice(s) refers to guidance(s) or recommendation(s) offered about prudent future action. Scientist gave advice to teacher about the supervision as shown in the fieldnote below:

> *Ben told Sharon that he would not be able to come early, and he instructed the students to come early to run the rotatory evaporation of ethanol from crude extract. Thus, he suggested whether Sharon could advise the students alone or not. Sharon advised Ben that this suggestion might not be appropriate as she needs Ben to monitor students to operate the instrument and take safety aspects into account.*
>
> (Observation, Activity 2, 12.06.2018, Event 11)

Based on the event above, the advice given by scientist address the need of teacher to help scientist to monitor students during the experimentation. In addition, researcher found that there might be challenge for teacher commit to the collaboration which could be considered to study in further.

Teacher also gave advice to scientist to improve the interaction after evaluating the interaction between scientist and students:

> *Ben discovered that Sharon often delivered the instruction to himself. "Sharon, just talk to my students what they need to do next.", Ben suggested Sharon to deliver the instruction to students.* (Observation, Activity 1, 11.06.2018, Event 7)

Teacher might hope that scientist could frequently interact with students. Simultaneously, teacher also gave advice to students:

After that, Ben advised students Mark and Clark to ask Sharon if there is any inquiry and clarification of procedures and treat them as learning opportunity. "I think you all need to approach Sharon often," said Ben.
(Observation, Activity 1, 11.06.2018, Event 7)

After listening to teacher's advice, I thought we should frequently interact and approach madam (Sharon) and Dr. Mary to gain more knowledge and opinion from them.
(Reflection, Mark)

It appeared evident that teacher observed the interaction between scientist and students during the PPbl in this study. Teacher hoped that both parties, which were scientist and students respectively could achieve maximal and optimal interaction to reach the educational goal of STSC-PPbl as expected in this study as shown in the memo below:

When I realized that Sharon kept giving the instruction to me and I would need to deliver the instruction to students to do the lab works, I felt that there was no direct interaction between scientist and students. What I hoped to see was to create an environment or even a chance for students to meet, talk and interact with scientist. (Memo, Researcher)

This reflected the function of teacher as the *facilitator* of interaction between scientist and student in this study by contributing and structuring the interaction between the scientist and students so that the learning community of scientist, teacher and students were able to function effectively and produce high quality of science learning for students. Such act of facilitation made by teacher may indicate the belief and attitude of teacher and facilitator to achieve the goal of maximum interaction between scientist and students during PPbl.

(e) Give hints

Some of the control functions played by scientist or teacher manifested total transfer of information to students, i.e. the full package of information provided to students. However, some control functions could also be "partial transfer of information" during the learning process, i.e. scientist or teacher delivered the information or knowledge by giving hints to elicit the prior, existing memory or knowledge within the students as shown in the fieldnote below:

> *"What can you observe for this bioassay if the antioxidant is working? The colour change….?" Asked Sharon.*
> *"Purple to yellow". Answered Mark.*
>
> (Observation, Activity 4, 29.06.2018, Event 10)

Scientist checked students' knowledge by asking questions rather than deliver the information totally. Students underwent training and infused with basic knowledge by teacher as mentioned in Chapter 3. The knowledge or information obtained during the infusion could be stored as memory by students. Scientist could use some 'hint word' like *"colour change?"* in this event to recall the knowledge reside in students' memory. This reflected the pedagogical function played by scientist in this interaction. Teacher could also help scientist to recall the knowledge by also providing hints:

> *" Try to remember what I have taught you. What are the types of antioxidant capacity assays? Which type of bioassay does DPPH belong to? What are the working principles underlying this bioassay?" Ben was trying to give hints to students to recall the information.*
>
> (Observation, Activity 4, 29.06.2018, Event 9)

Teacher gave the hints by using questioning strategy with a more proper sequences to elicit the memory resided in the minds of students in a more organized way (starting from type of antioxidant capacity assays, followed by categorizing DPPH assay and lastly working principles). This questioning strategy deployed by teacher supplemented scientist's questioning strategy to direct students to elicit the memory to answer the question. In comparison with direct question posed by scientist, teacher reflected his function as science education pedagogical expert as he was able to demonstrate the strategy of questioning for elicitation of memory or knowledge in relative organized manner.

(f) *Provide guidance and supervision*

In this study, supervision refers to act to direct, manage, or oversee, while guidance is the advice or information aimed at resolving a problem or difficulty, especially as given by someone in authority, in this case, scientist and/or teacher. Even though there is distinctive difference between supervision and guidance, both functions shared the same goal to help students acquire science process skills as discussed below.

Both scientist and teacher provided guidance collaboratively to students to master the handling technique of apparatus during the experimentation as shown in the fieldnote below:

> *Sharon and Ben guided students in choosing the micropipettes until they were familiar of doing this.* (Observation, Activity 4, 29.06.2018, Event 11)

It is apparent that students faced problem or difficulty in choosing the micropipette to transfer the tiny amounts of solutions. The final goal of this control function played by both scientist and teacher was to allow students to carry out the experimentations independently with minimum guidance and supervision. In this study, researcher found that scientist provided minimum supervision as shown:

> *Sharon and Ben stood aside and let them to work on it.*
>
> (Observation, Activity 3, 19.06.2018, Event 8)

It appeared evident that students needed more time and repetitive practices of laboratory techniques or instrument operations to master the procedural knowledge. At this stage, scientist and teacher could just *'stand aside'* to monitor students' experimentation works. Supervision was still needed, even at minimum level, due to safety concern perhaps.

(g) Give reminder

Teacher reminded students to pay attention to the aspects that might be neglected by students to execute the experimentation properly as shown:

> *Teacher reminds them about some steps they have neglected during weighing process as he noticed that students were unaware of that.*
>
> (Observation, Activity 4, 29.06.2018, Event 4)

(h) Make decision and justification

With the *control* function of scientist, students had chance to refer to literature and decide on their condition of experiments. By making such decision, students needed to provide their justification to scientist as shown:

"Madam, I found some literatures stated that the drying temperature should be around 60º C," said Clark. "Why?" asked Sharon. "This is to assure the phytochemicals inside the algae would not decompose due to this temperature," answered Clark. (Observation, Activity 1, 11.06.2018, Event 2)

In a nutshell, control functions of 'give instruction', 'give solution', 'give suggestion', 'give advice', 'give hints', 'provide minimum supervision' , 'give reminder' and 'make decision and justification' revealed how participants direct or regulate, either verbally or by behavioral approach, to assure the completion of task, planning or solving problem. From cognitive perspective, control functions allowed MKO to organize and elicit the knowledge of novice to answer the questions.

4.2.2.3 Evaluation

Evaluation functions are the functions that show inferential and optative characteristics during the interactions, including process of action itself, self and others motivation and outer situations (Bales, 1950). These functions, for instance, comprise of giving opinion, evaluation, analysis, expresses feeling, wish etc. In this study, four themes emerge include 'give view or opinion', 'know progress', 'ask questions', 'make observations or monitoring' as discussed below.

(a) Give view or opinion

It was unavoidable to have different kinds of views or opinions expressed by participants during the interaction. Scientist expressed her view on the scientific practice did by students during experimentation as shown in the fieldnote below:

After putting all the chopped algae into conical flask, students were asked to transfer 1.5 liter of ethanol into conical flask. At first, students attempted to measure the volume of ethanol accurately. However, Sharon said that there was unnecessary to measure it accurately in this step.

(Observation, Activity 2, 11.06.2018, Event 3)

Scientist gave her view on the measurement of volume of ethanol for cold soaking method in ethanolic extraction of hot spring algae (*unnecessary for accurate measurement)* which contradicted students' practices (*necessary for accurate measurement)* as observed during interaction. In this event, researcher made the clarification on the view of scientist as depicted below:

In extraction process, the volume of solvent used is not the variable to be controlled since the extraction process would be repeated for several times to ensure complete extraction of phytochemicals.

(Researcher's note, Observation, 11.06.2018)

Somehow it appeared evident that there could be difference in executions of scientific practices between real-world practicing scientist in research context and students who learned science in school context. This differentiated the school science from authentic science by some means. This might be due to students were taught to follow the instruction from scientist (authority) or procedures written on the science experiment lab manual exactly during science teaching and learning process. Scientist understood the rationale of the procedure thus she could make the statement of *unnecessary for accurate measurement* as clarified by researcher which this trait was not shown by students.

Besides that, teacher shared his opinion or view with students on their observation as shown:

He (Clark) smelled the sample and tried to compare what he did at home He (Clark) tried to dry the algae sample by using sun drying, but it looked smelly. He (Clark) shared his opinion with teacher(Ben), saying that "The algae look like seaweed now, it is so smelly". "I don't think it is smelly, it *smells like seaweed now", said teacher(Ben). He smelled again, "indeed, it is so different with what I've tried before,", said Clark.* (Observation, Activity 2, 12.06.2018, Event 5)

Students also gave opinion to the occasion happened during the experimentation. During the sampling process, there was a man showed objection to their sampling process. Two students responded differently to the objection:

> *"I understand what uncle is trying to say, "said Tom*
> *"Actually, I couldn't understand what the difference between the sampling method we used and suggested method by uncle actually. Both are practical. "said Thomas.* (Observation, Activity 1, 19.06.2018, Event 18)

The sharing of opinions between teacher and student, or among students as shown in the fieldnotes above showed the characteristic of negotiation during process of science learning. Two different types of opinion or view (*smelly* and *not smelly*; *understand* and *couldn't understand*) were brought by them for open discussion.

(b) Know progress

Scientist also played her evaluation function to know the progress of experimentation as shown:

> *Sharon came to visit Tom to understand the progress of work.*
> (Observation, Activity 2, 13.06.2018, Event 14)

Scientist tried to understand the progress of student's work of experimentation during the visit. In a primarily objective way, this fieldnote showed that scientist was evaluating student's work as the object of evaluation during the interaction.

(c) <u>Ask questions for evaluation</u>

Scientist evaluated students' knowledge by asking them questions as shown:

> *"Before I proceed, I would like to ask what you know about DPPH bioassay?" asked Sharon. ...*
> *"Okay, I go and take the manual and give you several minutes to think", said Sharon. (After few minutes)*
> *"Tell me about what you know about DPPH" asked Sharon.*
> *"It involves redox reactions" said Clark.*
> *"Yea." Nodded Sharon. They remained silent.*
> *"DPPH is the radical." Said Mark.*
> *"Yea." Nodded Sharon.*
>
> (Observation, Activity 4, 29.06.2018, Event 9-10)

In this function, scientist checked students' knowledge about the procedures of experimentation. Teacher also checked students' knowledge by asking questions as shown"

> *Teacher asked students why we need to chop the algae into smaller pieces before putting them into conical flask for ethanolic extraction.*
> (Observation, Activity 2, 11.06.2018, Event 2)

Both scientist and teacher checked students' knowledge by using questioning strategy as teaching and learning method during these interactions. These signpost the priority of students' understanding on the procedural knowledge before the executions of procedures during the experimentations.

(d) <u>Make observation or monitor</u>

Both scientist and teacher made observation on students' learning conditions during experimentation as shown in the fieldnote below:

Ben and Sharon observed that they could not choose suitable micropipette to measure the varying volumes of the solutions required. ...
(Observation, Activity 4, 29.06.2018, Event 11)

In this event, students were required to transfer the tiny amounts of solution (up microliter) by using different types of micropipettes (with different types of volumes) to 96-well plate. Students were facing difficulty in selections of suitable types of micropipette. To execute this task and assure students mastered this skill, both scientist and teacher provided guidance collaboratively (as reported in *control* functions) to reach the level of mastery of handling techniques of apparatus based on the observation made.

Besides that, teacher also made observation on the interaction condition between scientist and students before providing advices for improvement as reported in *control* functions in [Obs, A1, E7].

To conclude, evaluation functions of ‘give view or opinion’, ‘know progress’, ‘ask questions’ and ‘make observations or monitoring’ played by participants during the interactions provided them opportunities to internalize the current situations or information received and externalize through verbal expressions of opinions or views and questioning to improve their own understanding during the interaction.

4.2.2.4 Independency

Independency is seen as one of the important traits that the students need to have in conducting experiments or executing tasks with the scaffolding provided both scientist and teacher. When students were able to think, act and execute the task without or with minimum support provided by scientist or teacher, they were said to reach the level of independency at certain extent in this study. In other words, there was little or no supervised learning conditions for students to acquire science knowledge and skills during the process of collaboration and interaction, making this theme to be distinctive from 'control' subarea. Researcher identified the theme of *independency* from two dimensions: behaviors and cognition as will be discussed in the following.

The independency identified from the behaviors when students improved the quality of subsequent experimentation on steps of task execution after experiencing the initial stage of experimentation with the guidance of teacher as shown in the fieldnote below:

> *Without any clear instruction from Ben, they (Clark and Mark) took out all the equipment needed from the car, then started to choose which hot spring they would like to sample the algae. "Which pond has better quality of algae?", "These algae look fresh, I want this!", "How much do we need?" "Sample them as much as possible!" Clark and Mark conversed to each other.*
>
> *They took the sampled algae, looked at their appearance (examining the algae). "Why there is a brown part appeared in algae? Can we sample it?" asked Mark. "No, choose the greener one!" replied Clark.*
>
> (Observation, Activity 1, 11.06.2018, Event 10)

This was the second time of sampling of hot spring algae. Since students were getting familiar with the methods of sampling now, they started to pay focus on selecting better quality algae for their study, figuring out the quantity of algae needed and the expected appearance of the sampled hot spring algae.

Event below also shows that students improved the laboratory techniques during the experimentation process as shown in the fieldnote below:

> *They (Clark and Mark) discovered the weakness of the previous method of cleaning algae samples and adapted it to better one by putting the clothes beneath the sieve to prevent wastage of algae samples for study.*
>
> (Observation, Activity 1, 11.06.2018, Event 11)

In this event, students evaluated the previous method of laboratory technique and they used their own idea to improve the method based on the weakness they found after having first experience with the guidance from scientist. The strategy of adaptation of laboratory technique for improvement could be said as signpost of *independency* of students during the learning process.

Besides that, student took initiative to progress their practical works showed independency as shown in the fieldnote below:

> *"Teacher, we start to clean the algae first," said Mark and Clark. Mark and Clark started the cleaning works soon. They clean the algae samples independently without waiting step-by-step instruction from Ben.*
>
> (Observation, Activity 1, 11.06.2018, Event 11)

Students also followed up the progress of experimentation and continued it as described in Activity 2, Event 10 and 22. Besides that, student could execute the tasks independently such as cleaning the laboratory after lab works (Activity 1, Event 5 and 9) cleaning samples (Activity 1, Event 6). Students operated the instrument independently upon the guidance of teacher (Activity 2, Event 13). All these observed behaviors indicated that students proceeded the experimentation without prior instructions from scientist and/or teacher, showing the traits of *independency* in this study.

Besides that, traits of *independency* were also observed as the object of cognitions from students. STSC-PPbl also engaged students in active thinking which is one of the components of active and independent learning:

Thomas observed the fluctuation of the temperature of the chiller. They looked at the rotavap and started thinking about the function of rotatory evaporator. "Teacher, you see the temperature of chiller is increasing, and the ethanol is evaporated and condensed into collecting flask," said Thomas.

(Observation, Activity 2, 14.06.2018, Event 17)

Student operated the instruments and the observation that he made triggered his thinking. Then, he started to pose questions to teacher to increase his own understanding, indicating the science learning happened. This could be the part of active thinking illustrated by student as the question he asked portrayed that he was engaged to the interaction with the instrument as external stimulus.

Reflection on experimentation could also be one of the traits of *independency* as the object of cognition from students. The fieldnote below shows independency of students when they reflected on their performance during experimentation.

They (Students) observed the mixture was cloudy grey initially and they <u>assumed</u> that ethanol does not contain any extract from hot spring algae. However, once they performed filtration, they found that the filtrate appeared green in colour. ("It is actually green!"). They found that they were <u>too fast to infer</u> the observation as it contradicted the initial observation.

(Observation, Activity 2, 14.06.2018, Event 15)

I slowly reflect on our problem ... (Reflection, Thomas)

Initially, students made assumption based on their belief that was the third time of successive ethanolic extraction of hot spring algae. After they observed the appeared green colour in the filtrate, they reflected on their assumption made and claimed that they were too fast to make inference. From 'assumption' to 'claim, there might be the process of reflection as the object of cognition during such transition. The interaction between students and the context (process of filtration) engaged them in this process without instruction from scientist and students, which could be reported under the category of *evaluation* and *independency* during the interaction.

To summarise, the traits of independency emerged during the interaction in this study can be categorized to two dimensions: (a) behaviours through improved procedures during experimentation and initiative to progress the practical works and, (b) object of cognition through active thinking and reflection on the experimentation. All these elements gave chance to students to develop independent learning skills during the interaction with context of PPbl such as instruments and process of experimentation with minimal aids from MKO.

Table 4.1-4.3 below shows the parts of the summary of interaction functions of scientist, teacher, and student in neutral task area functions (Refer Appendix C).

Table 4.1 Active roles of scientist in neutral task area functions

Task Area	Theme		Description	Direction	Evidence
Orientation	Give confirmation	-	During question and answer session	To students	Obs, A2, E2
Control	Give solution	-	Overcome the problems emerged during experimentation	To students	Obs, A1, E4 Obs, A2, E1 Obs, A3, E6 Obs, A4, E5
Evaluation	Give view	-	scientific practices during experimentation	To students	Obs, A2, E3

Table 4.2 Active roles of teacher in neutral task area functions

Task Area	Theme	Description	Direction	Evidence
Orientation	Have discussion	- Improve quality of practice	To students	Obs, A1, E10
Control	Give advice	- Improve the direct interaction between scientist and students	To scientist and students	Obs, A1, E7
Evaluation	Make observation	- Interaction conditions between scientist and students	To scientist and students	Obs, A1, E7

Table 4.3 Role of students in neutral task area functions

Task Area	Theme	Description	Direction	Evidence
Orientation	Asks questions	- Ask for information	To peers	Obs, A1, E13
Control	Give suggestion	- Time planning	To teacher	Obs, A1, E8
Evaluation	Give opinion	- Sharing	To teacher and peers	Obs, A1, E5,18
Independency	Improve quality of practice	- Experimentation		Obs, A1, E10.11 Obs, A3, E6

4.2.3 Role of Scientist, Teacher and Students in Neutral Task-Related Functions: Comparison and Variation

In this section, the roles of scientist, teacher and students in neutral task area were determined and described by further abstraction and generalization of interaction data pertaining to neutral task-related functions as reported above. Researcher compared the neutral task interaction functions of scientist, teacher, and students to give the general idea of role of participants during the interactions through the synthesis of illustrations. In short, the aim of this section is to tie up the interaction functions of all the participants by comparison to see the similarities and variations during the role play of participants during interaction.

4.2.3.1 Emerging characteristics of role of participants in STSC-PPbl

At first, researcher first identified the characteristic of functions(s) of scientist, teacher, and students during STSC-PPbl in this study by carefully examining the interaction data as reported in the previous section. The overview of emerging role of scientist in this study was scientific practice expertise, teacher as education practitioner and facilitator while students as novice learners during interaction as shown in Figure 4.5. There were some interaction functions were played collaboratively by both scientist and teacher which can be characterized as 'co-teaching' with 'one teaches, one assist and facilitate' approach in this context. The following section would depict the detailed characteristics of each role played by scientist, teacher and students by comparing and contrasting the interaction data using several synthesized illustrations, for instance, interaction effect from scientist or/and teacher to students and vice versa, as well as differentiated functions played by teacher.

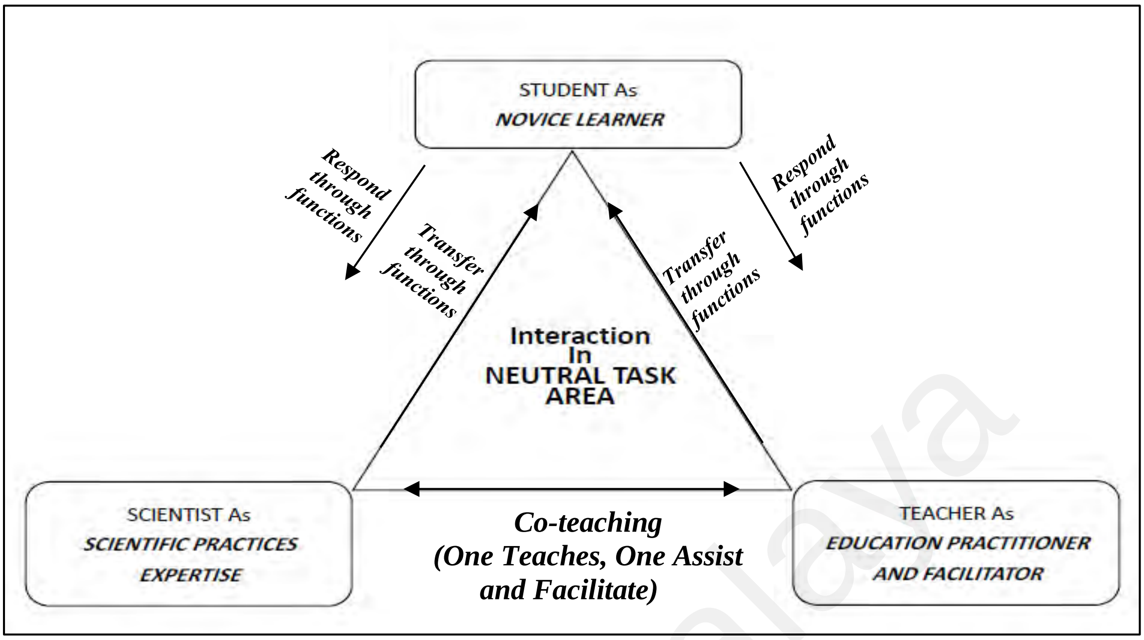

Figure 4.5 The overview of role of scientist, teacher, and students during experimentation in neutral task area-related functions

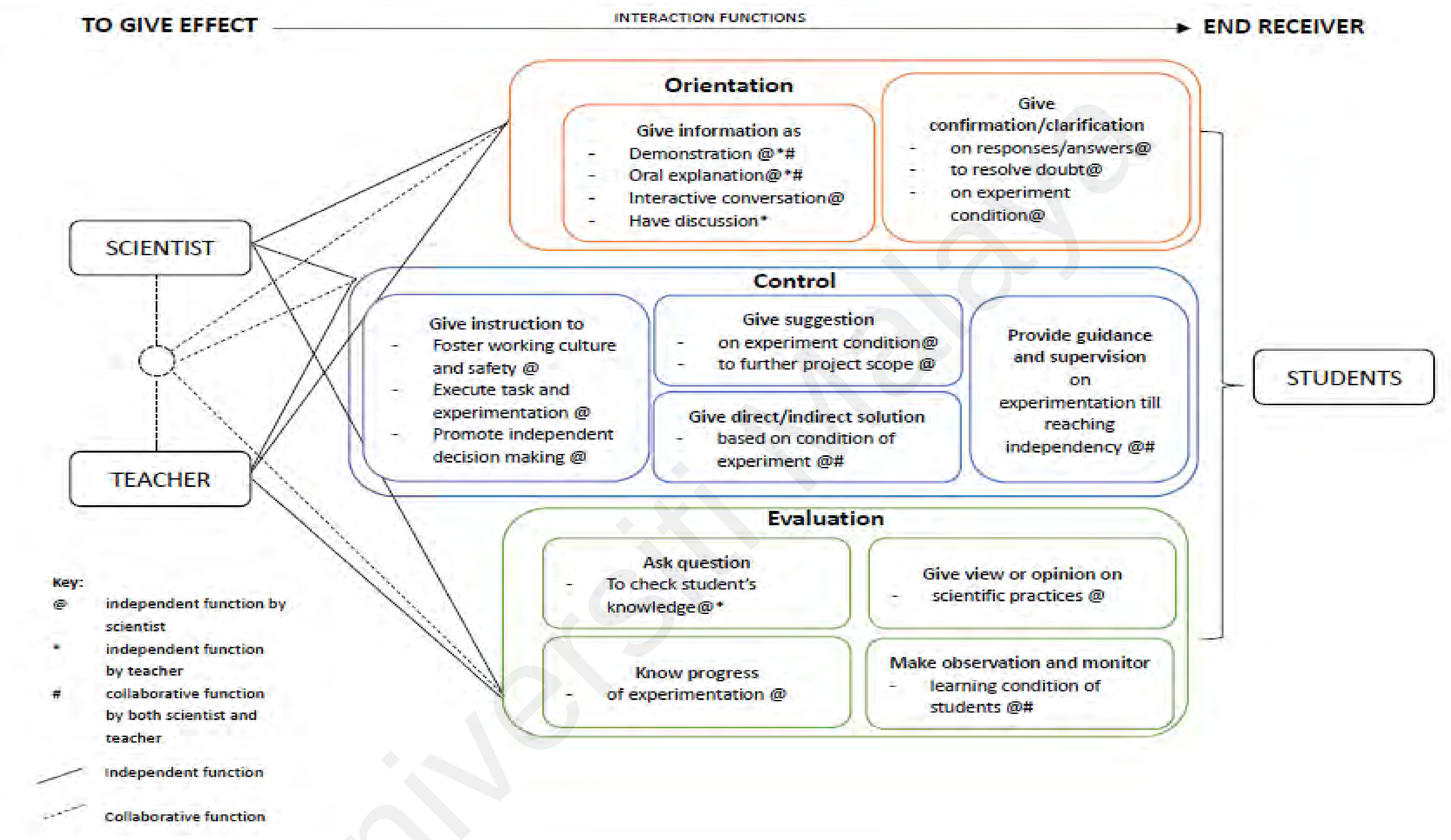

Figure 4.6 Synthesised illustration to picture the interaction effect from scientist or/and teacher to students in neutral task areas

Figure 4.6 shows the synthesised illustration to picture the interaction effect from scientist or/and teacher to students in neutral task areas. In general, both scientist and teacher adopted "collaborative teaching" or "co-teaching" during STSC-PPbl in this study. In another words, both scientist and teacher, as certified professionals of scientific research and science education respectively, who shared instructional responsibility for this group of students in the authentic context, i.e. research laboratory with mutual ownership, pooled resources and joint accountability (Friend and Cook, 2016).

After the careful examination of interaction patterns and functions as shown in Figure, the co-teaching approach adopted by scientist and teacher was "One Teaches, One Assist and Facilitate". In this approach, scientist kept primary responsibility for teaching scientific research practice while teacher circulated through the collaboration teaching session providing unobtrusive assistance to students and facilitation of interaction process as needed.

In this study, scientist assumed primary responsibility for teaching scientific research practice to students which is "One Teach" in the co-teaching in this study. In term of orientational functions, scientist gave information as demonstration, oral explanation, had interactive conversation, and gave confirmation and clarification on responses and answers given by students and experiment conditions, as well as to resolve doubt from students. In term of control functions, scientist gave instruction to foster working culture and safety, execute task and experimentation as well as promoting independent decision making by students. Besides that, scientist gave suggestions to students based on experiment conditions and to further project scope, as well as provide solutions to problems encountered. Scientist also provided guidance and supervision on students until they reached independency. In term of evaluation functions, scientist asked questions to evaluate students' understandings, got to know the progress of experimentation, give view or opinion on scientific practices, and observed and monitor students' works. All these functions played by scientist throughout the interactions in this study reflected her role as scientific practise expertise. It appeared evident that all the functions played by scientist was to allow the transfer of procedural knowledge of scientific research practice to students during the interaction.

Teacher circulated through the collaborative teaching session providing unobtrusive assistance and facilitation of interaction process to students as needed which is "One Assist and Facilitate" in the co-teaching in this study. With reference to Figure 4.6, teacher played parts of the neutral task-related functions as compared to scientist. It is noteworthy that there were some differentiated interaction functions played by teacher which reflected his role as both 'education practitioner' and 'facilitator' as shown in Figure 4.7. As education practitioner, teacher gave instruction to students to assure task completion, which was different as compared to scientist who gave instruction for task execution and experiemntation. During the experimentation, teacher gave reminder to students so that they would take note on some neglected aspects. Teacher also asked questions to evaluate students's understanding like scientist did. However, when scientist asked students questions, teacher gave hints to students for elicitation of memory in organised manner to assist students in answering questions. All these functions revealed that teacher hoped to play his role to assure the interactions during collaboration to achieve the goal of science learning by students. As facilitator of collaboration, teacher observed the condition of interaction and facilitated it by giving advice to both scientist and students to maximise the intensity of direction of interaction by both parties. In sum, such differentiated functions played by teacher assumed his roles as "One Assist and Facilitate" during the co-teaching approach with scientist in this collaboration.

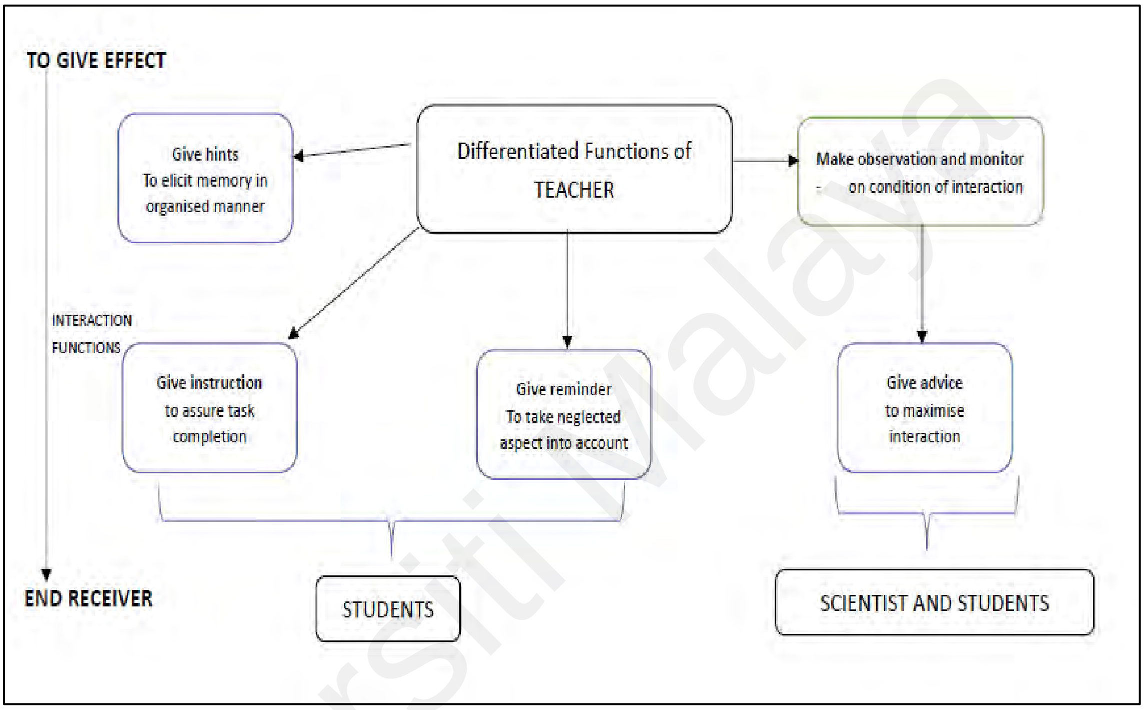

Figure 4.7 The differentiated functions played by teacher during STSC interaction

Based on Figure 4.6, researcher noted that there were some collaborative interaction functions could be played by both scientist and teacher during co-teaching process during the collaboration in this study. These functions include orientational functions (such as demonstration, oral explanations), control functions (such as provide solutions to problems, provide guidance and experimentation) and evaluation functions (observation and monitoring of students' works). The collaborative functions played by both scientist and teacher tended to complement each other to give more optimal interaction effects to students.

In addition, researcher also intended to know what kind of interaction effects imposed by students during the collaboration. Figure 4.8 shows the synthesised illustration to picture the interaction effect from students to scientist or/and teacher in neutral task areas.

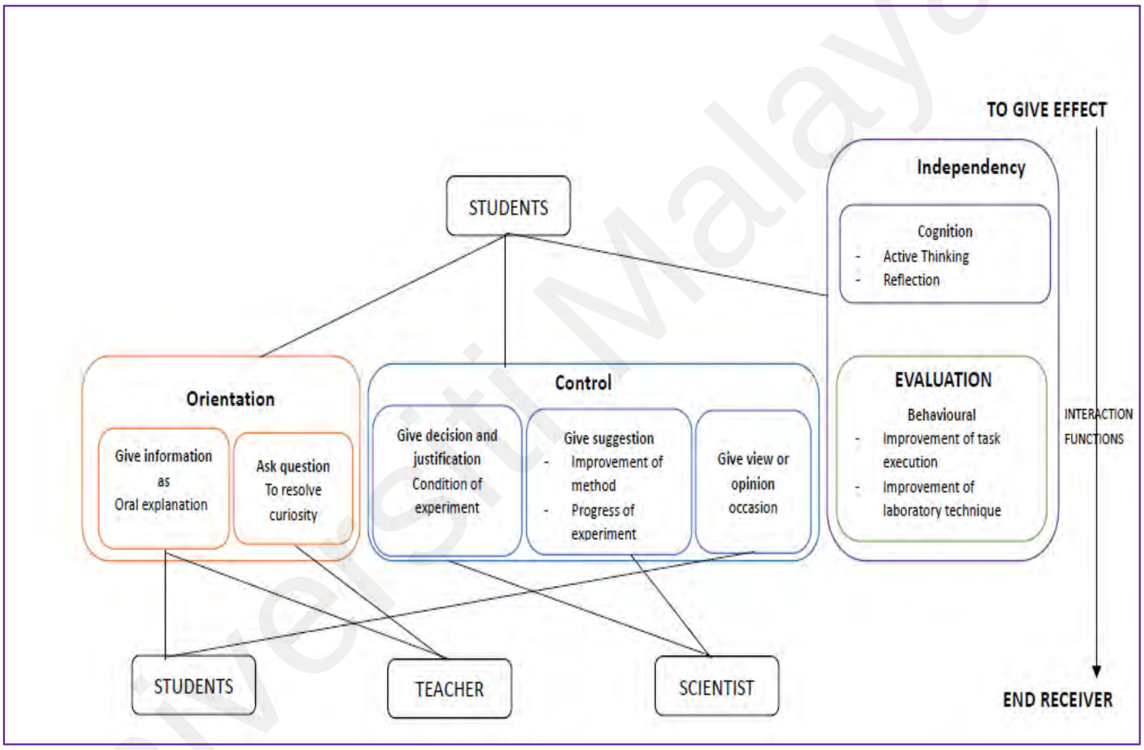

Figure 4.8 Synthesized illustration to picture the interaction effect from students to scientist or/and teacher in neutral task areas

Based on Figure 4.8, students played major role in orientational and control functions to all the participants (scientist, teacher, and students) and reached independency as an emerged theme during the interaction process analysis. The orientational functions include gave oral explanations to students and teachers, and asked questions to resolve their curiosity. In term of control functions, students gave decision and justification on the condition of experiments, gave suggestion to improve the procedures and further the progress of experiments and expressed their opinion on occasions. By looking at the independency as the emerged theme and important traits, researcher categorized the interactions functions as cognitive (engagement in active thinking and reflection) and behavioral (improvement of task execution and laboratory techniques).

4.2.4 Socioemotional areas

Socioemotional area is the analysis area related to an individual's emotions and relationship to society. In this study, researcher conceptualized this term into the analysis of scientist, teacher and students' emotions and relationship to collaboration group during STSC-PPbl in this study.

There are several dimensions to investigate socioemotional areas of interaction in this study: (1) *positive* versus *negative* evaluation; (2) *strong* versus *weak* characterization and (3) *active* and *passive* impression (Scholl, 2013) which serve as fundamental dimensions of interaction as enacted by humans in various cultures. Researcher employed '*positive versus negative evaluation'* of socioemotional areas, which is in line with Balesian perspective, to identify the types of emotions exhibited by participants to explore the types of emotions emerged by participants during the data analysis of participant observation notes in this study.

There are three subareas in socioemotional areas investigated in this study namely *decision, tension management* and *integration*.

4.2.4.1 Decision

The *decision* function refers to the *socioemotional effects* due to action, behavior or reaction manifested by participant to another participant during the process of decision-making. Researcher investigated the socioemotional interaction during the process of decision-making by participants through examining participant observation notes during STSC-PPbl in this study. There are two elements emerged under this area: show agreement and disagreement.

In Activity 2, Event 18, students felt difficult to transfer the sample from the surface of glassware as it was sticky. Thus, a student suggested the addition of little amount of solvent (ethanol) to the sample to ease the transfer. This suggestion was viewed as the decision made by students in this section as shown in the reflection below:

> *We put too much ethanol* [decision] *and need to run the rotavap again …*
> (Reflection, Thomas)

However, this decision brought two different reactions, showed disagreement and agreement from both scientist and teacher respectively as shown:

> *Ben agreed and few drops of ethanol was poured were dropped into evaporating flask.*
> *Sharon came and disagreed with the practice because too much ethanol would affect the accuracy of bioassay test. …*
> (Observation, Activity 2, 14.06.2018, Event 18)

Such reactions could be viewed as the socioemotional effects on students' decision-making in this study. Such reactions in decision-making can be viewed as contexed with feeling of the 'voice of science' (agreement and disagreement). The reactions of agreement and disagreement aroused could be attributed to different knowledge by default or background of both scientist and teacher in this study. Teacher explained this situation as shown in the memo below:

> *I thought it was fine just adding little ethanol to dissolve the extract that sticked on the surface on the glass wall.* (Researcher's note, Memo)

Nevertheless, students and teacher eventually followed scientist's disagreement and did the evaporation again as shown in the reflection above. This might be due to the role of scientist as scientific practice expert in this study. By another way of saying, this also revealed that the process of decision-making in STS interaction followed scientist as the authority. Figure 4.9 shows visualization of the STS interaction in *decision* function which shows the process of reaching decision using the 'voice of science'

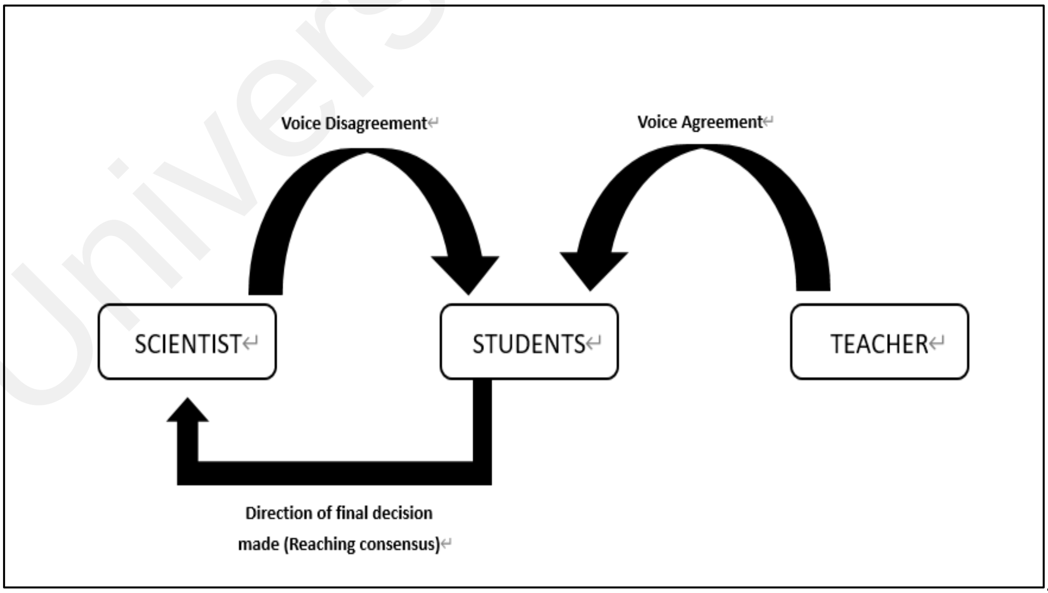

Figure 4.9 Visualization of interaction pattern of decision function in this study

The decision of students changed due to instruction on scientific practice imposed by scientist to students during experimentation as shown:

> *At first, students attempted to measure the volume of ethanol accurately. However, Sharon said that there was unnecessary to measure it accurately in this step. "Oo… okay okay…" Students first hesitate, knitted their brows* [b.h. – facial expression] *and followed Sharon's suggestion.*
>
> (Observation, Activity 2, 11.06.2018, Event 3)

The socioemotional effect aroused when students felt hesitate and might be showing some *disagreement* to scientist's opinion (would be reported later). This might be due to students were thinking why scientist gave the suggestion which was quite different from the scientific practice acquired in the school science syllabus that required them to make *accurate* measurement. However, students did not show passive rejection as they *followed Sharon's suggestion*. This further confirmed the role of scientist as scientific practice expert and authority in this study.

4.2.4.2 Tension management

Tension could be viewed as "stress" in social interaction (Dissing *et al.,* 2019). It could be diffuse tension, diffuse anxiety, shame and guilt, frustration, asking for help or permission and withdrawal out of field (Bales, 1950). Researcher would like to explore the tensions aroused during the interaction between scientist, teacher, and students in this study. In this subarea, There were two categories of observations on tension managements: (1) tension aroused within students due to shyness/reluctance, lack rapport, unexpected condition during experimentation, difficulty to understand knowledge, accidents, questioned by scientist, problem during experimentation and concern to safety aspect as supported from relatively high intensity as reported in SEP; and (2) tension released done by teacher through showing care and give demonstration. To report the findings in this section, researcher explicitly labelled the behavioural response (b.h.), facial expression (f.e.) and experiential feeling (f), which are the parts of components of emotions, as illustrated in the excerpts

In general, researcher found that several tensions aroused by students during the interaction process as well as the process of experimentations in this study. Firstly, there was a tension when students first met the scientist as shown in the fieldnote below.

> *At first, students felt shy and reluctant* [f.] *to introduce themselves to scientists. When Cheng asked Mark and Clark to greet and introduce themselves to Sharon, they just stood still, looked at Ben* [b.h.] *and smiled.*
> (Observation, Activity 1, 11.06.2018, Event 3)

Clark further clarified the feeling of shyness and reluctance during the introduction session during the first acquaintance with scientist in the reflection below:

> *We were not familiar with madam (Sharon). It was difficult for me to take initiative to talk to her, therefore I just looked at her and smiled.* [f.e.]
> (Reflection, Clark)

Also, researcher found that there was a tension when students would like to take the initiative to interact with scientist:

> *Students first hesitate to do so* [f.] *but started to interact with scientists ...*
> (Observation, Activity 1, 11.06.2018, Event 7)

Thus, there might be no rapport between scientist and students at initial stage of collaboration fostered, thus the tension was observed in this activity before reaching optimal interaction for successful collaboration sessions which worth discussion.

The non-ideal or unexpected conditions of experimentation also created tension to students as shown in fieldnotes below:

> *Tom discovered that the samples collected were not adequate. Tom sighed.*[b.h.] *He tried to transfer the dry algae samples stacked on the surface of aluminum foil and tried to make up the inadequacies of number of dry algae samples. "Oh no, we need to do sampling again," said Tom.*
> (Observation, Activity 1, 13.06.2018, Event 16)

> *They weighed the samples. "0.5 gram only?" said Clark. "It is equivalent to 500 mg". said Thomas. "Is it enough to run the tests?" worried Clark.*
> (Observation, Activity 2, 14.06.2018, Event 20)

The tensions faced by students due to non-ideal or unexpected conditions of experimentation were said to be a usual challenge for scientist. It was apparent that students tried to avoid the non-ideal or unexpected conditions of experimentation and showed worry to them.

The tension created when students were trying to understand the knowledge that related to the projects, experimentation, scientific practices, or instrumentation.

> *Students knit their brows,*[f.e.] *having difficulties in understanding blank, positive and negative control in bioassay.* (Observation, Activity 4, 29.06.2018, Event 12)

> *"Madam, I don't understand why we need to reflux the mixture, rather than just soaking the hot spring in water just like ethanol extraction?" asked Mark.*
> (Observation, Activity 3, 19.06.2018, Event 3)

The tension was also created when accident happened during experimentation.

> *During the removal of evaporating flask, Mark broke the glass and the samples were wasted. Mark felt sad and sorry* [f.]. *Sharon came and comfort the students, saying that perhaps the evaporating flask was hot and slippery. It was an accident and unexpected* (Observation, Activity 2, 14.06.2018, Event 19)

Mark accidentally broke then round bottom flask… (Reflection, Thomas)

I was stunned [f.] *when I broke the round bottom flask …* (Reflection, Clark)

Clark accidentally broke the glassware … (Reflection, Thomas)

Tension might be experienced by students when scientist checked their knowledge by asking them questions as shown in the fieldnote below:

> *Sharon asked for the rotation per minute (rpm) needed to use for shaking. Mark and Clark stood still and looked at Sharon*[b.h.].
> (Observation, Activity 2, 11.06.2018, Event 4)

This might be due to students did not know what *rpm* is and did not have adequate knowledge to answer the questions asked by scientist. Another excerpt manifested the tension as shown:

> *Before I proceed, I would like to ask what you know about DPPH bioassay?" asked Sharon. Students stunted* [f.] *and looked* [b.h.] *at the teacher.*
> (Observation, Activity 4, 29.06.2018, Event 9)

The feeling of *stunted* as illustrated by students could indicates the tension was created within students. Researcher observed that the act of students looked at the teacher could be seeking the assistance from teacher.

Tension created when students faced problem during the process of experimentation.

> *They found the process of transferring samples from the surface of evaporating flask was not easy as the sample produced was dry and stick to the surface of round bottom flask. They knit their brows*[f.e.]*, showed their "stressful" faces*[f.e.] *during the process of transferring samples.*
> (Observation, Activity 2, 14.06.2018, Event 18)

> *I was trying hard* [b.h.]*to scratch the samples from the wall of round bottom flask. Unfortunately, the samples were not scratched out completely.*
> (Reflection, Clark)

Teacher and I scratched the contaminated sample. (Reflection, Thomas)

Students showed tension could be due to show concern to safety aspects during experimentation as shown in the fieldnote below.

> *"Watch out, teacher! Stay careful. It's hot. Use your hand to hold the bottom of flask before removing it to avoid breakage." "No…no…no…" worried* [f.] *Tom even though Ben was able to remove the flask correctly and safely.*
>
> (Observation, Activity 3, 19.06.2018, Event 9)

Perhaps student had witnessed the breakage of glassware by his friend during the removal of flask from instrument as reported in the participant observation. When he needed to execute the task, he became extra careful and tension was created when he looked at others to execute the same task. This indicated that the awareness of safety aspect was created within students based on the experience from observing accident by peers.

Besides looking at the tension aroused, researcher also noted the functions played by MKOs that contribute to tension release by students. First, teacher showed care to student to show tension release.

> *After a period, "Do you feel tired of doing this?" asked teacher. "No, I was so happy* [f.]*to see my sample will be produced now after this," said Clark with smile* [f.e.]. (Observation, Activity 2, 12.06.2018, Event 9)

The act of show care by teacher by asking student whether he was exhausted could be categorized as *integration* function (would be reported later). The facial expression of *smile* showed by student might be the indication of tension release from doing the experimentation.

Students took initiative to seek the acts of tension release by asking for teacher's demonstration before achieved the stage of tension release as shown in the fieldnote:

> *"Teacher, I would like to see you to do first," said Clark.*
> (Observation, Activity 2, 12.06.2018, Event 7)

Then, student showed tension release by self when he was able to operate the laboratory technique or instruments independently during the process of experimentations as shown in the fieldnotes below:

> *He* <u>*became more confident*</u>[f.] *as he could run the filtration and successive extraction alone after going through first hands-on experience yesterday.*
> (Observation, Activity 2, 12.06.2018, Event 6)

> *I felt* <u>*less nervous*</u> [f.] *once I familiar with the operation of rotatory evaporator ...*
> (Reflection, Tom)

The transitions from "tension" due to first hands-on experience to "tension release" such as increased level of *confidence* and feeling of *less nervous* due to increasing familiarity with the process of experimentations such as laboratory techniques and instrumental operations were observed by researcher and reported by student in their journal. Thus, it can be inferred that the tension release by students themselves could be made by prolonged engagements of students with process of experimentations in authentic context.

4.2.4.3 Integration

In sociology, integration refers to "the intermixing of people who were previously segregated" (Lexico.com, 2020). Bales (1950) states that integration includes shows solidarity, raises other's status, gives help and reward. In this study, researcher conceptualized the term to "mixing" of a party of participants to another party of participants through socioemotional functions and interactions. There are six elements of integration functions include 'facilitation', 'show friendliness', 'give praise', 'give assistance/guidance', 'give encouragement' and 'accompany'.

The act of facilitation by teacher for greeting and introduction of students to scientist or vice versa was one of the integration functions in socioemotional areas as shown in the fieldnote below:

> *Ben asked Mark and Clark to greet and introduce themselves to Sharon, they just stood still, looked at Ben and smiled. Sharon was friendly to students and asked Mark and Clark to stay relax and calm to reduce the number of mistakes during the practical works.* (Observation, Activity 1, 11.06.2018, Event 3)
>
> *I was awakened about a saying from Dr (Sharon): "It is okay to make mistakes; it doesn't work every time, but we are here to try.*
> (Reflection, Tom)

It was apparent there was a tension for students to introduce themselves to scientist (as categorized in *tension management*). Perhaps they felt shy or were not familiar with the scientist:

> *We were not familiar with madam. It was difficult for me to take initiative to talk to her, therefore I just looked at her and smiled.* (Reflection, Clark)

In this case, scientist showed solidarity or friendliness to students to release the tension (as categorized in *tension management-tension release)*. Scientist also explained the reasons of why students need to stay relax and calm for the sake of smooth practical works. The act of show solidarity or friendliness could be one of the integration functions played by scientist to "integrate" students into STS learning community. From this analysis, researcher found that the association of positive integration functions and positive tension management functions are associated to help students to resolve the tensions.

Besides that, researcher also observed that scientist gave praise to students for his capability to communicate.

> *Sharon praised Tom as he was able to communicate more fluently using English relatively. Tom smiled and continued his job.*
> (Observation, Activity 2, 13.06.2018, Event 14)

> *I am not nervous about the communication between scientist and I because I am confident about my English proficiency. … Sharon looked friendly to me and she praised me.* (Reflection, Tom)

The act of giving praise from scientist to student for his strength (for example, in this case, the English language communicative ability) gave the status-raising effect to student.

The integration function could be manifested during student-student or peers interaction as shown in the fieldnote below:

> *Clark taught Thomas and Mark to operate the rotatory evaporator to evaporate the ethanol from the extract. Clark explained the working principle to Mark and Thomas, and he was now able to guide them to operate the instruments. They worked collaboratively to operate the instruments. Both Mark and Thomas were given the main role in operating instrument,*

meanwhile Clark stay by their sides to assist and gave instruction to them when necessary.

(Observation, Activity 2, 14.06.2018, Event 16)

Today, I taught Mark and Thomas how to conduct experiments. Everything was smooth. (Reflection, Clark)

I observed some instruments meticulously and curious about their functions. I kept asking Clark and Mark… Clark demonstrated the operation of rotatory evaporator which looked similar with reflux. I operated with Mark once I understood the principle. (Reflection, Thomas)

I consulted Clark. He taught me how to use the tissue paper to absorb the water.

(Reflection, Tom)

It was apparent that Clark had mastered the knowledge and procedures of instrument operation. In other words of saying, Clark was the MKO who more familiar with the operation of instrument than others. So, this could be a chance for Clark to provide guidance to his peers to master the knowledge and procedures of instrument operation. The way Clark guided his friend was same with how teacher guided Clark to master the operation of instrument as reported above. Perhaps Clark learned the way of guidance provided by teacher and turned it into practice while guiding the peers.

The encouragement provided by teacher to students to use their science knowledge learnt in science classroom to provide explanation is said to integrate students to the context of learning.

Ben encouraged students try to explain the principle of reflux based on what they learnt and understand in the chemistry classroom. Then, Clark offered himself to do it. (Observation, Activity 3, 19.06.2018, Event 4)

Clark has bravely explained the working concepts of reflux and I recorded it.

(Reflection, Mark)

Teacher accompanied students to do practical works throughout the STSC-PPbl. The act of teacher to prompt students to give information about the instrument based on the prior knowledge aimed to promote maximal engagement and interaction between students and the context of the study. The compliment given by the peer for student's attempt to explain the principle of instruments operation as shown in the reflection also gave status-raising effect to the student.

Scientist and teacher provided guidance to students when they did not master the procedural knowledge completely.

> *Ben and Sharon observed that they could not choose suitable micropipette to measure the varying volumes of the solutions required. Sharon and Ben guided students in choosing the micropipettes until they were familiar of doing this.*
>
> (Observation, Activity 4, 29.06.2018, Event 6)

The guidance provided by both scientist and teacher was considered as "give help" in IPA which is considered as one of the integration functions. Besides that, the reflections below show teacher gave help to students during practical works.

> *Teacher was willing to offer himself to help us filter ...* (Reflection, Mark)

> *Teacher and I scratched the contaminated sample ...* (Reflection, Thomas)

Researcher identified the 'accompany' as elements of integration functions from the reflections of Mark and Thomas. This can be reflected when teacher escorted students through his partial involvement during the process of experimentation along with students. This might be important for causing comfort in students during the process of learning. This can further extend the function of teacher as accompanying facilitator during STSC-PPbl.

As reported in *orientation* function, the act of teacher helped scientist to offer explanation to students can be viewed as *integration* function from socioemotional perspective as shown in the fieldnote below:

> *"Ben, could you please explain to your students about this?" said Sharon. "Sure, every colour has its own wavelength in visible spectrum. DPPH gives purple colour which has the wavelength of 519 nm. The more DPPH radicals are scavenged, the less intense the purple colour solution. From there we can know the antioxidant capacity of our extract." Explain Ben.*
>
> (Observation, Activity 4, 29.06.2018, Event 6)

The act of asking for help from scientist to teacher was to assist scientist during the transmission of information to students. Perhaps scientist perceived that teacher could explain the knowledge that make student understandable, or scientist lacked this knowledge to offer clearer explanation. Again, teacher reflected his role as pedagogical expert in transfer of knowledge to students as depicted in this event. Teacher helped scientist to explain the knowledge to students was considered "give help" in IPA which is considered as one of the integration functions. This implied scientist and teacher worked together collaboratively as a learning community to co-teach students during STSC-PPbl.

4.2.5 Structural Exchange Pattern of Scientist-Teacher-Students Collaboration

To answer the second research question in this study, researcher employed structural exchange pattern analysis (SEP) adapted from Fahy (2001) on STSC-PPbl in authentic research setting. The basic structural features of the STSC-PPbl in this study described the characteristics of the collaboration itself. From this analysis, information about the scope for potential interaction, as well as data on the actual extent to which individuals connected and interacted in this collaboration were depicted. The SEP analysis was done in this study by simply quantifying and summing up the qualitative codes of each event in the activity through simple statistical treatment (Anwar, 2015) to picture the structural elements in the interaction. The findings from SEP analysis gave the picture to the researcher the pattern of interaction during STSC-PPbl in this study.

4.2.5.1 Density of Interaction

The density of interaction calculated in this study is 6.4 (a=64, N=5). This indicates that the degree of connection between scientist, teacher and students is sufficient in this study. It is worth to note that the density of interaction is sensitive to the size of group (Fahy, 2001). The larger the size of group, the smaller the value of density of interaction. It also reflects the degree of interactions prior to analysis by researcher by breaking down the bigger activities (parts) into smaller events (pieces) from participant observation notes for IPA and coding. The higher the density of interaction, the higher the degree of interaction prior to analysis and the more the events of collaboration were scrutinized by researcher in this study.

4.2.5.2 Intensity of Modes of Interaction

The intensity of modes of interaction refers to how frequent the interactions between three parties of participants (scientist, teacher and students) in either at unipartite (interaction took place within single party) or multipartite (interaction between parties) with reference to the density of interaction (which was affected by the value of *a*). Researcher assigned the labels of modes of interactions (e.g. bipartite) to the events of each activity based on the code assigned (e.g. scientist-students). Then, the intensity of modes of interaction of STSC-PPbl was calculated by quantifying and summing up each mode of interactions. Figure 4.10 shows the intensity of multimodal interaction during STSC-PPbl.

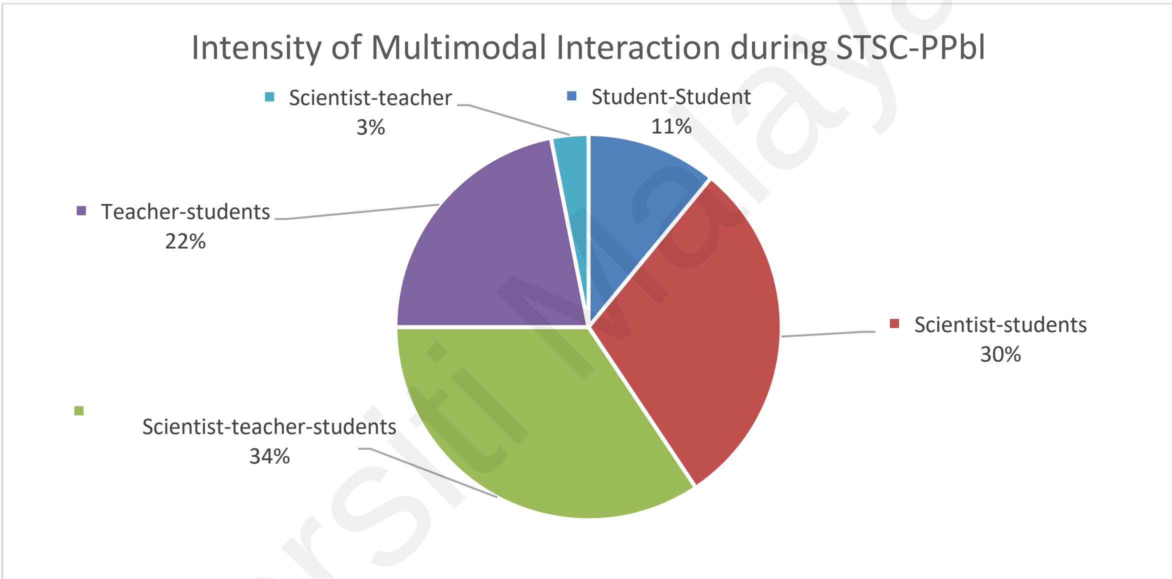

Figure 4.10 Intensity of modes of interaction during STSC-PPbl

There were three modes of interactions with their respective code(s) identified in this study: unipartite (student-student), bipartite (scientist-teacher, scientist-students, teacher-students) and tripartite (scientist-teacher-students). Overall, scientist-teacher-students interaction recorded highest percentage (34%) followed by scientist-students (30%), made up the overall 64% for the opportunity for students to have direct interaction with scientist in this study. This indicates that the expected direct interactions between scientist-students were achieved. Teacher-students interaction recorded 22% from overall intensity, followed by interactions among students (11%). Scientist-teacher interactions marked the lowest percentage of the intensity of interaction (3%).

4.2.5.3 Intensity of Interaction Functions

The purpose of depicting the interaction functions of each participant in this study was to understand the major functions and played by them and its distributions during the interactions, either at neutral task or socioemotional area. The intensities of interaction functions of each area were calculated by quantifying the labels (*active, passive, positive,* or *negative*) and expressed in the form of percentage. Researcher noted different participants had different number of tasks counts, however the frequency counts do not indicate the nature, quality, or relevance of the role of participants, instead this analysis provided indications for researcher to identify the pattern of interactions in this study (Gorse and Emmit, 2005) (Refer to Table B and C in Appendix E)

4.2.5.3.1 Intensity of Neutral Task Area, Active to Passive Task Ratio and Independent Task Ratio of Students

Intensities of neutral task area of each participant including scientist, teacher and students are to show the proportions role of each participant in orientation, evaluation, and control functions, either active or passive role, during the interaction in STSC-PPbl. The proportions of neutral task area of each participant were calculated by quantifying the codes of "active" and "passive" of all events (Refer to Appendix D). Simultaneously, the active to passive task ratios of neutral task areas of each participant and independent task ratio of students were calculated. Figure 4.11-4.13 shows the neutral task area interaction analysis of scientist, teacher, and students respectively (Refer to Table B n Appendix E).

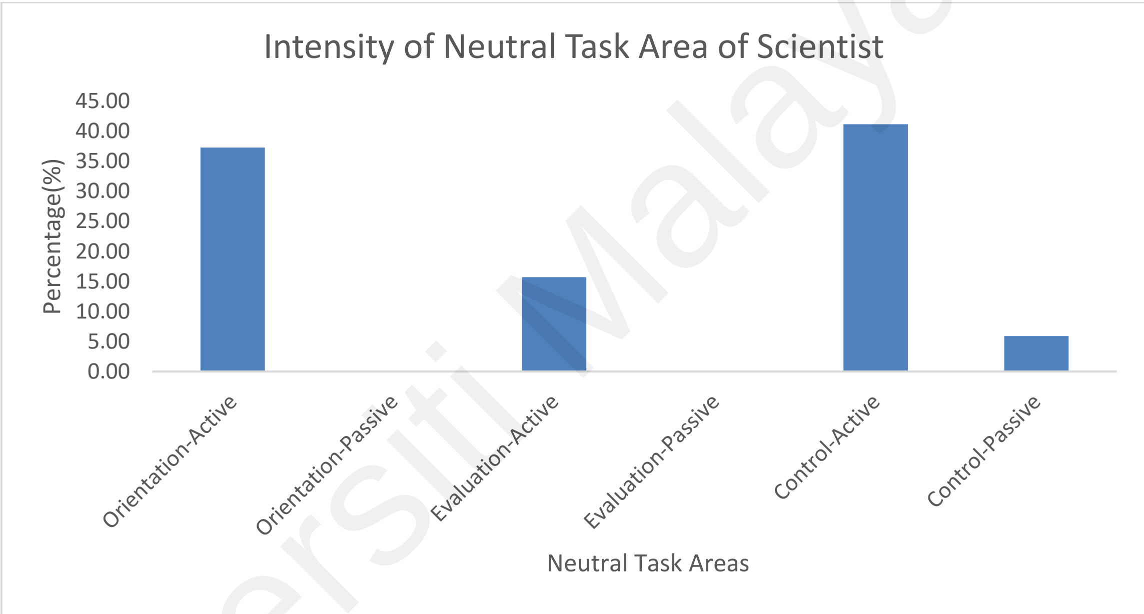

Figure 4.11 Intensity of neutral task area of scientist in this study

Figure 4.11 shows the intensity of neutral task area of scientist during STSC-PPbl by categorizing fifty-one labels (active and passive) assigned prior to the open codes given to each description of all activities. Scientist played major functions in active role in control functions such as give instruction, solutions, hints, advices, suggestion, supervision and guidance (41.18%), followed by active role of orientation which includes give clarification, confirmation and information to teacher and students

(37.25%). Scientist played least in active role of evaluation functions includes give views, know progress, ask questions, and make observation and monitor (15.69%). All the passive roles in three functions were not included in the discussion as researcher would like to know the active roles of scientist during the interaction. The active to passive task ratio of scientist in neutral task areas is 16.001:1. All these intensities and ratio calculated had corroborated scientist's role as scientific research and procedure expert in this study as reported in qualitative findings as mentioned above.

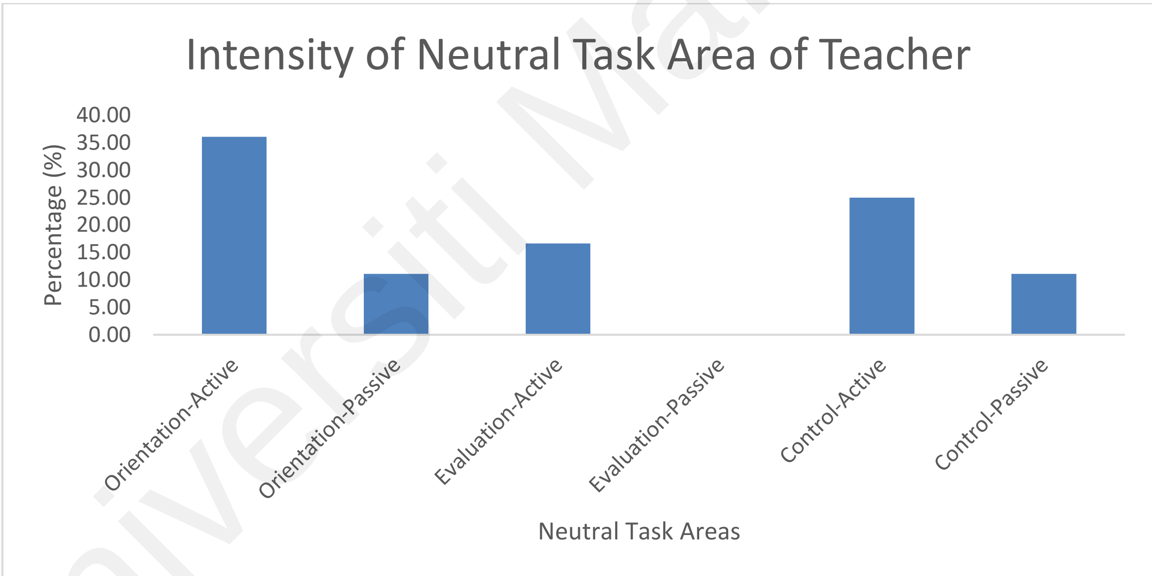

Figure 4.12 Intensity of neutral task area of teacher in this study

Figure 4.12 shows the intensity of neutral task area of teacher during STSC-PPbl by categorizing thirty-four labels (active and passive) assigned prior to the open codes given to each description of all activities. Teacher played major functions in active role of orientation which includes give information, as well as discussion to teacher and students (36.11%), followed by active role in control functions such as give instruction, solutions, hints, advices, suggestion, supervision and guidance (25.00%). Teacher played least in active role of evaluation functions includes give views, know progress, ask questions and make observation and monitor (16.67%) All the passive roles in three functions were not included in the discussion as researcher would like to know the active roles of scientist during the interaction. The active to passive task ratio of teacher in neutral task areas is 3.50:1. All these intensities and ratio calculated had corroborated teacher's role as education practitioner and facilitator in this study as reported in qualitative findings as mentioned above. Based on the ratio calculated, the active role played by teacher is smaller than scientist, which could be due to the nature of role of teacher to assist scientist during co-teaching, which supported the concept of "One Teach, One Assist and Facilitate" in this study.

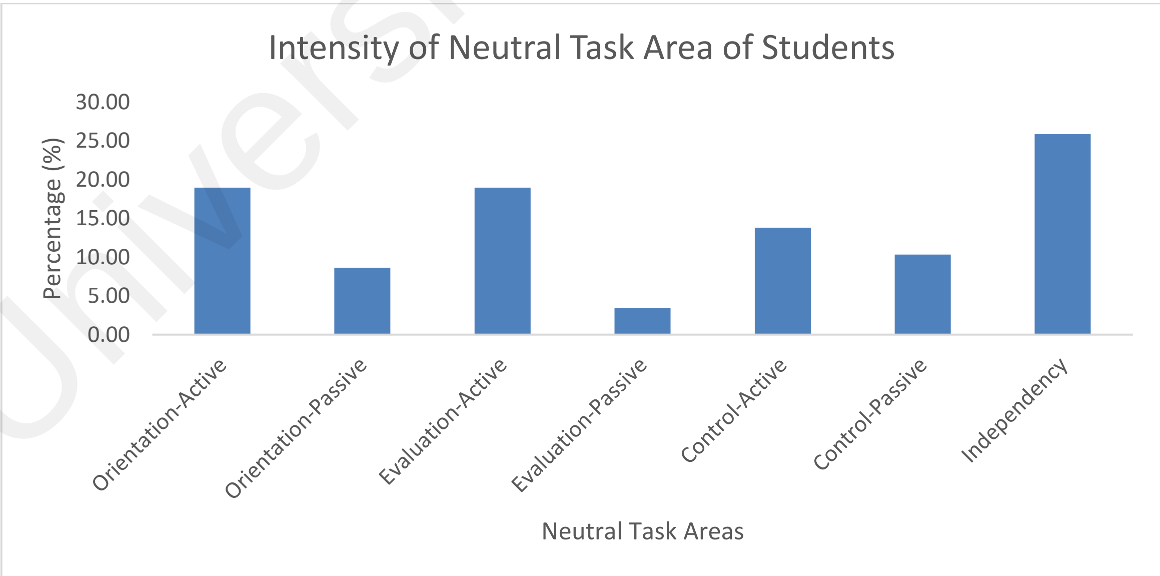

Figure 4.13 Intensity of neutral task area of students in this study

Figure 4.13 shows the intensity of neutral task area of students during STSC-PPbl by categorizing fifty-eight labels (active and passive) assigned prior to the open codes given to each description of all activities. Students took both major active roles in orientation functions such as ask questions to increase understanding, asks for information etc. and evaluation function (18.97%), followed by control functions such as give suggestion, give decision and justification (13.79%). Researcher also identified independency of students as emerging neutral task areas such as improve quality of experimentation practice, progress the practical works, independent task execution, independent operation of instruments and active thinking (25.86%). Researcher categorized independency as active role played by students during interaction in STSC-PPbl. The active to passive task ratio of students in neutral task areas is 3.46:1 while the independent task ratio calculated is 0.35:1.

4.2.5.3.2 Intensity of Socioemotional Area and Positive to Negative Socioemotion Ratio

Intensity of socioemotional area of each participant including scientist, teacher and students is to show the proportions role of each participant in integration, tension management and decision functions, either positive or negative during the interaction in STSC-PPbl. The proportions of socioemotional areas of each participant were calculated by quantifying the labels of “positive” and “negative” of all events. Simultaneously, the positive to negative ratios of socioemotional areas of each participant were calculated. Figure 4.14-4.16 shows the socioemotional areas interaction analysis of scientist, teacher, and students respectively (Refer to C in Appendix E).

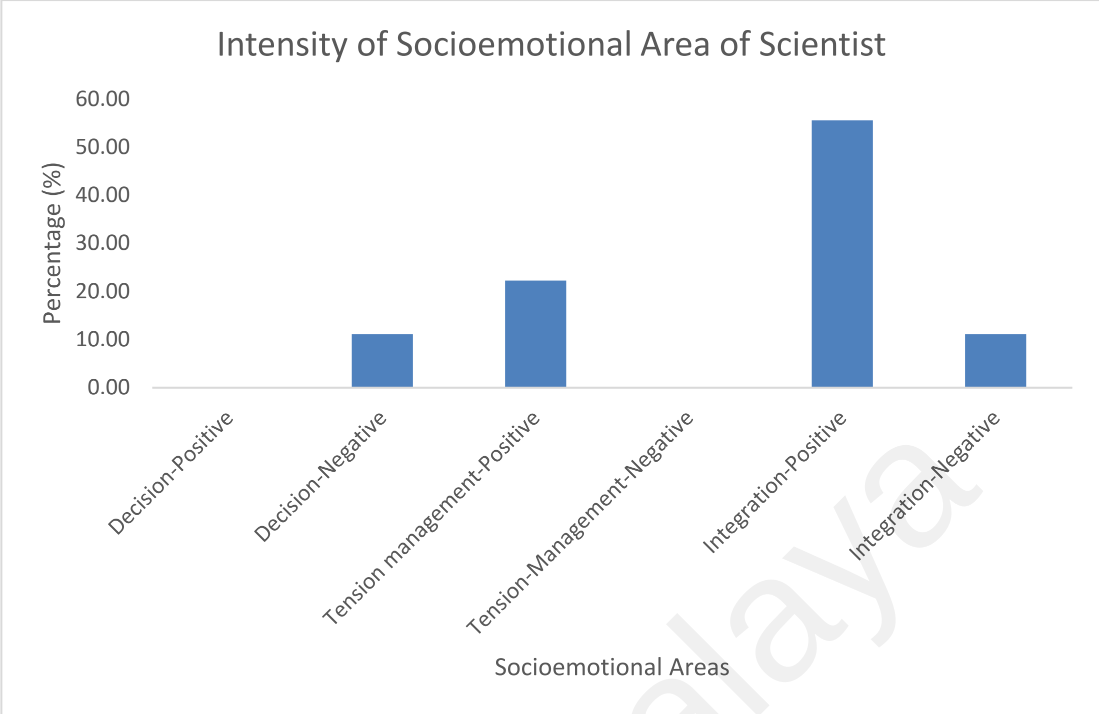

Figure 4.14 Intensity of socioemotional area of scientist in this study

Figure 4.14 shows the intensity of socioemotional area of scientist during STSC-PPbl by categorizing nine labels (positive and negative) assigned prior to the open codes given to each description of all activities. Scientist played major functions in positive functions of integration (55.56%), followed by positive functions in tension management (22.22%). Scientist also showed negative decision functions by showed disagreement (16.67%). The positive to negative functions ratio of scientist in socioemotional areas is 3.5:1.

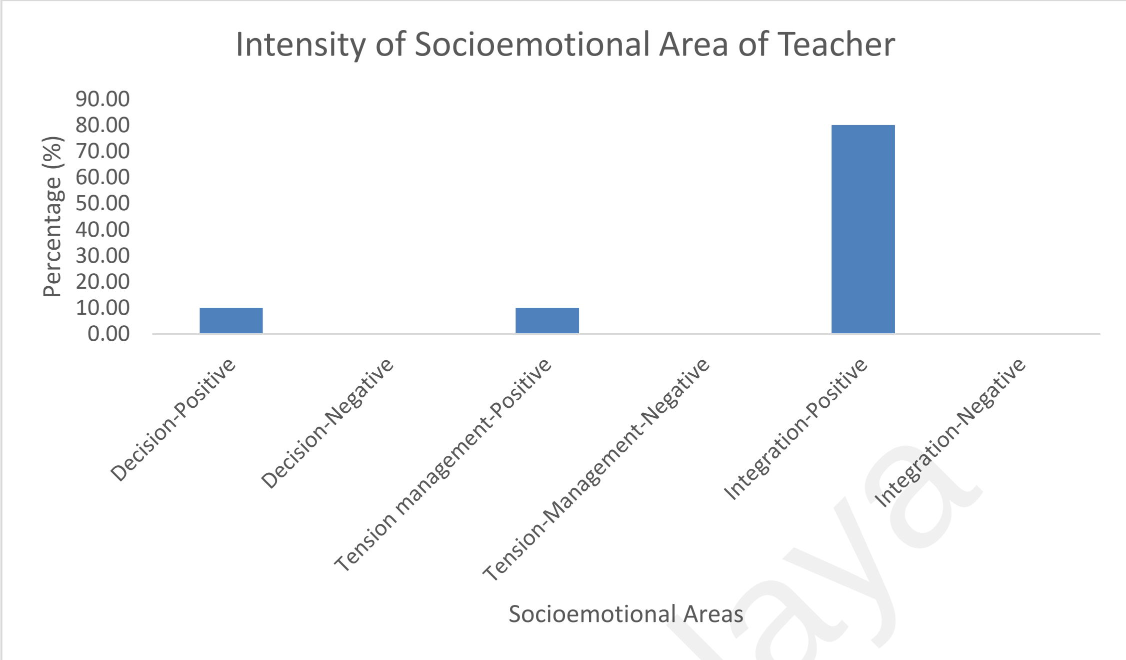

Figure 4.15 Intensity socioemotional area of teacher in this study

Figure 4.15 shows the intensiti of socioemotional area of teacher during STSC-PPbl by categorizing ten labels (positive and negative) assigned prior to the open codes given to each description of all activities. Teacher played major functions in positive functions of integration (80.00%), followed by positive functions in tension management (10.00%). Teacher also showed positive decision functions by showed agreement (10.00%). The positive to negative functions ratio of teacher in socioemotional areas is 1:0.

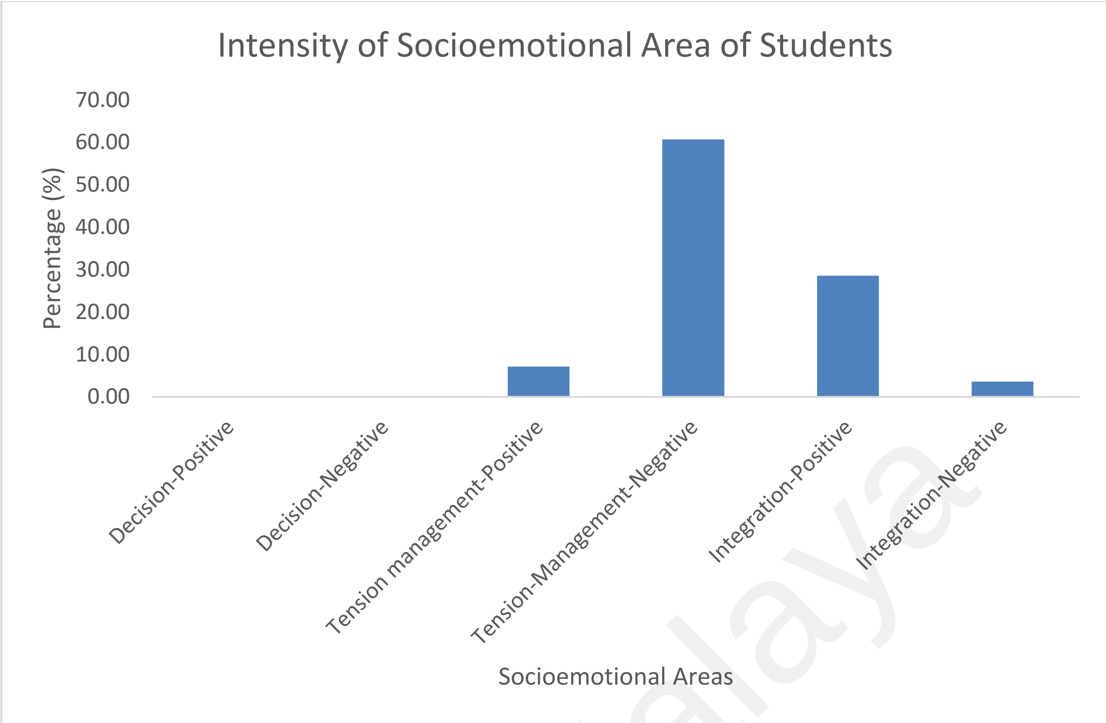

Figure 4.16 Intensity of socioemotional area of students in this study

Figure 4.16 shows the intensity of socioemotional area of students during STSC-PPbl by categorizing ten labels (positive and negative) assigned prior to the open codes given to each description of all activities. Students showed remarkable negative functions of tension management (60.71%), followed by positive functions of integration (28.57%) and positive function of tension management (7.14%). The positive to negative functions ratio of scientist in socioemotional areas is 0.56:1. The remarkable negative functions of tension management exhibited by students were corroborated by the qualitative findings as reported above such as tension when first met the scientist, accidents, doing mistakes, unexpected conditions etc.

4.3 Summary of Findings in this Study

In sum, the findings from neutral task areas of IPA, there were five themes emerged under orientation functions such as ‘give confirmation’, ‘give clarification’, ‘give information’, ‘have discussion’, and ‘ask questions’; eight themes emerged under control functions includes ‘give instruction’, ‘give solution’, ‘give suggestion’, ‘give advice’, ‘give hints’, ‘provide minimum supervision’ , ‘give reminder’ and ‘make decision and justification’; and four themes emerged under evaluation functions of ‘give view or opinion’, ‘know progress’, ‘ask questions’ and ‘make observations or monitoring’. One emerged theme of independency as a trait of independent learning achieved by students consists of two dimensions: (1) behavioural independency through improved quality of experimentation, procedural skills, and initiative of progressing practical works, and (2) object of cognitions includes active thinking and reflection which were correlated with the orientation and evaluation functions respectively. The overarching roles of scientist, teacher and students in neutral task area were depicted through synthesized illustration from interactionism perspective.

The findings from IPA on socioemotional area reported two elements of decision functions of ‘show agreement’ and ‘show disagreement’, and six elements of integration functions include ‘facilitation’, ‘show friendliness’, ‘give praise’, ‘give assistance/guidance’, ‘give encouragement’ and ‘accompany’. There were two categories of observations on tension managements: (1) tension aroused within students due to shyness/reluctance, lack rapport, unexpected condition during experimentation, difficulty to understand knowledge, accidents, questioned by scientist, problem during experimentation and concern to safety aspect as supported from relatively high intensity as reported in SEP; and (2) tension released done by teacher through showing care and give demonstration.

The findings from SEP also indicated sufficient opportunity for students to have direct interaction with scientist, with 64% of overall counted modes of collaboration in interaction events in this study. The density of interaction calculated of 6.4 might give indication about satisfactory degree of connection between scientist, teacher and students is sufficient in this study or sufficient amounts of observation recorded on the STS interaction. To make the statistical analysis of SEP meaningful, the in-depth qualitative study was reported to supplement the data.

.

4.4 Summary

This study generated interaction picture between scientist, teacher, and students during PPbl in authentic setting. Participant observation notes and reflective journals from students were among of the ways analyzed and described. The following chapter discusses how the emerged findings in this chapter answered the research questions of this study.

CHAPTER 5: SUMMARY, CONCLUSIONS, DISCUSSIONS, IMPLICATIONS AND RECOMMENDATIONS

5.1 Introduction

Chapter Five illustrated a summary of the entire study. Chapter Five summarizes the conclusions and discussions of the research questions. Besides that, this chapter also discusses the implication to the learning theories. Parallel to that, methodological reflections and scientist-teacher-students collaboration in problem-project based learning (STSC-PPbl) in authentic research setting's practicality, especially on how STSC-PPbl helped the teachers and policymakers were also discussed in this chapter. Recommendations of research were also displayed at the final section to conclude this chapter and the entire research study.

5.2 Research Summary

One of aims of science education is to make the science learning more appealing to students for college and work readiness in future, and indirectly inviting more students to pursue STEM-related degrees and careers to realise Malaysia's goal of becoming an industrialised and developed country (Saat, 2012). Students need to learn science in social context which will contribute to socio-scientific decision making in resolving issues and problems in society rather mere conceptual understanding to increase the relevance of science learning (Resnick, 1991; Packer & Goicoechea, 2000; Hsu & Roth, 2010; Eggert et al., 2013; Siribunnam et al., 2014). To support the call mentioned, inquiry-based instructions provided an impactful learning experience to students especially at secondary school level (Scruggs, et al., 2003; Mumba *et al.,* 2015; LaForce, Noble & Blackwell, 2017).

Authentic science learning which reveals high relevancy boost students' motivation, attitudes, and interest. It shows close connection between what students learnt in classroom and daily life phenomenon, or even real-world issues and problems. However, current pedagogy does not show how science actually works and teacher, who had no experience in doing scientific research, would revert the science process to teaching almost by rote (Alan et al., 2019; Fadzil & Saat, 2013; Rudolph, 2019).

This study answered the following research questions:

1. What are the interactions between scientist, teacher and students in problem-project based learning in authentic research setting?
2. What is the structural exchange pattern of identified interaction process between scientist, teacher and students in problem-project based learning in authentic research setting?

This study employed basic qualitative-exploratory research to investigate interaction process of STSC-PPbl in authentic research setting. The theoretical foundation of this qualitative study was based on situated cognition theory and Vygotsky's social constructivism views.

There were three phases of STSC-PPbl used in this study: (1) preparatory phase; (2) practical works and experiments and (3) science communications of findings and results. The focus of the study was on the interaction between scientist, teacher, and students in phase two. The observations on the STSC-PPbl interaction were made based on two analysis areas namely neutral task area and socioemotional area with total six subareas (orientation, control, evaluation, integration, tension management and decision) where the reporting was made in terms of interaction functions of participants. Both IPA and SEP supplemented each other to generate the overview of interaction pattern of STSC-PPbl methodically.

Based on the findings from neutral task areas of IPA, there were five themes emerged under orientation functions such as 'give confirmation', 'give clarification', 'give information', 'have discussion', and 'ask questions'; eight themes emerged under control functions includes 'give instruction', 'give solution', 'give suggestion', 'give advice', 'give hints', 'provide minimum supervision' , 'give reminder' and 'make decision and justification'; and four themes emerged under evaluation functions of 'give view or opinion', 'know progress', 'ask questions' and 'make observations or monitoring'. One emerged theme of independency as a trait of independent learning achieved by students consists of two dimensions: (1) behavioural independency through improved quality of experimentation, procedural skills and initiative of progressing practical works, and (2) object of cognitions include active thinking and reflection which were correlated with the orientation and evaluation functions respectively. The overarching roles of scientist, teacher and students in neutral task area were depicted through synthesized illustration from interactionism perspective.

The findings from IPA on socioemotional area reported two elements of decision functions of 'show agreement' and 'show disagreement', and six elements of integration functions include 'facilitation', 'show friendliness', 'give praise', 'give assistance/guidance', 'give encouragement' and 'accompany'. There were two categories of observations on tension managements: (1) tension aroused within students due to shyness/reluctance, lack rapport, unexpected condition during experimentation, difficulty to understand knowledge, accidents, questioned by scientist, problem during experimentation and concern to safety aspect as supported from relatively high intensity as reported in SEP; and (2) tension released done by teacher through showing care and give demonstration.

5.3 Conclusion

Incorporating relevant studies from the literature and the data from participant observations and reflective journals, this study explored the content and pattern of scientist-teacher-students interaction during problem-project based learning (STSC-PPbl) in authentic context through interaction process analysis (IPA) and structural exchange pattern (SEP) analysis. From the findings from SEP, the intensity of STS tripartite interactions indicated students were granted chance to directly interact with scientist as duo interaction or together with teacher as a trio interaction to complete the PPbl. The overarching findings from the IPA during the exploration of neutral task functions executed by participants during STSC-PPbl provided insights to depict the roles of scientist as scientific research experts and teacher as education practitioner and facilitator as collaborative duo in "one teaches, one assists and facilitates" manner. As a certified professional in science research practice, scientist took the major role in transferring science knowledge and procedural skills to students through various orientation, control and evaluation functions as supported from the findings from SEP. Surprisingly, the findings from IPA illustrated the supportive role played by teacher in facilitating the learning process and interaction between scientist and students in this context for optimal science learning outcome. The differentiated functions manifested by teacher to students such as gave instruction for assurance of task completion, gave reminder to make students stay attentive to neglected aspects, gave hints for elicitation of memory, and promoting scientist-students interaction supported this contributive role. In this study, teacher could also be the novice to acquire scientific research knowledge from scientist despite students.

The exploration of socioemotional functions executed by participants during STSC-PPbl provided insights on how socioemotion of scientist, teacher and students affected each other during the interaction. The findings indicated the unavoidable negative tensions created within students due to various conditions such as first meet with scientist, unexpected occasions, accidents, problems during experimentation and questioned by scientist were noteworthy, supported with high intensity from SEP findings. Besides tension release and integration functions played by scientist and teacher to release the tensions of students, researcher suggested it is worthwhile to be opportunistic about negative tensions as the triggers of learning, and pay more attention make them becomes the drivers of learning through appropriate interactive strategies deployed by scientist and teacher. Besides that, the overarching interaction on decision functions revealed the characteristics of authentic context of this study through situating students into the agreement and disagreement reactions showed by teacher and scientist, respectively.

Moreover, this study raises additional questions related to the research topic. For examples, what are students' reflections, experiences and learning outcomes associated with participation in STSC-PPbl? How do these experiences and learning outcomes vary? What is the extent of information received and organization of knowledge gained by the students in this STSC-PPbl? What are the perceptions of students on this STSC-PPbl? From scientist's and teacher's perspective, how do they perceive their professional growth in this collaboration? It is hoped that future researchers can reference to the findings from this study and investigate these questions on the topic of scientist-teacher-students interaction in authentic environment. These investigations are contributive and supportive to the improvement of quality of interaction during STSC, as well as students' science learning in this collaboration.

5.4 Discussion

This study aimed to answer two research questions: "What are the interactions between scientist, teacher and students in problem-project based learning in authentic research setting?" and "What is the structural exchange pattern of interaction process between scientist, teacher and students in problem-project based learning in authentic research setting?" Researcher employed participant observation and reflective journals from students to collect data and analyzed by analytical framework adapted from Bales's (1950) Interaction Process Analysis and Fahy's (2001) structural exchange pattern analysis. The findings were presented in thematic manner. This section discusses some findings to be compared with relevant past studies. Researcher also discussed how the study can be used to further the knowledge in collaboration between scientist, teacher, and students.

Nature of Interaction in STSC-PPbl in this study

Humans learn from social interaction as posited by Vygotsky. In other words, social interactions promote construction of knowledge. Interactions between humans reveal certain extent of complexity and intricacies. Rigorous and systematic picturization of interaction patterns between humans could be challenging. Most of the educational research involved two parties of interactions in science learning context, for example, teacher-students (Leder, 1987) and scientists-students (Woods-Townsend *et al.,* 2015; Hsu, 2018). However, when the number of parties of participants increases (more than two), the patterns and directions of interactions would be getting complex and intricate (Peker & Dolan, 2012). Researcher realized that the understanding on interaction pattern between scientist, teacher and students should be uncovered for meaningful science learning in terms of behaviors, dynamic and nature of STSC-PPbl. Thus, in this study, an analytical framework of interaction analysis adapted from Bales (1950) and Fahy(2001) provided the foundation for understanding the interaction and its pattern between scientist, teacher and students during STSC-PPbl, thus answered the research questions in this study. With this understanding the science education stakeholder could improve the design of interactive strategies that are critical to the success of STSC-PPbl for optimum science learning by students in future.

The analysis of the interactions between scientist, teacher, and students, which aimed to answer the first research question of this study, revealed that the nature of the interactions in this study had characteristics echoed and consistent with Borresen, (1990), Dees (1991), Keeler and Steinhorst, (1994) and Reglin (1990) 'unstructured collaboration' between participants, which there can be guidelines in a collaboration session, but there are no strict rules. Scientist, teacher, and students were free to interact with each other and researcher observed the interaction that "happened naturally". As mentioned earlier, researcher expected "triangular form" of collaboration mode in STSC-PPbl at which all parties of participants could maximally interact with each other during science learning. Researcher also expected there could be maximum intensity mode of direct interaction between scientist and students as one of the goals in this study. All these expectations have affected the role play by researcher as teacher in this study. To examine these expectations, besides analysing interaction elements, researcher also attempted to visualize the structural exchange pattern by quantifying the interaction elements (Bales, 1950, Fahy, 2001) as indications for understanding interaction. Based on the findings from interaction elements and structural exchange pattern analysis, the intensity of scientist-teacher-students interaction calculated was 35.56%. Based on this mode of interaction intensity, scientist, teacher, and students directly interacted with each other to certain extent. However, researcher suggested that the scientist-teacher-students interaction intensity could be increased during the design of STSC-PPbl, especially in Phase One and Three (which were not the focuses of this study), that involve active and direct engagements of scientist, teacher and students in future study. This is to assure maximal epistemological involvement of students in authentic science learning which students can experience the science research process more thoroughly.

Based on the reflective journals from students, the stereotypical views of scientists as individuals in lab coats who pose "stressful" image on them before the collaboration (Woods-Townsend et al., 2015; Finson, 2002; Barman, 1999; Chambers, 1983). In this study, it appeared evident that students grabbed opportunity to directly interact with scientist to work on a project during STSC-PPbl. Students could really engage with practising scientist to expose them with scientific practices as conducted for future college and work readiness. This provided students more realistic view of scientists and their works (Woods-Townsend et al., 2015, Besley & Tomner, 2011, Christidou, 2010; Christidou & Kouvatas, 2013). Learning with and from scientists (Hodson, 2012) through face-to-face interactions with scientists allowed students to view scientists as approachable, ordinary people, and start to understand the range of scientific areas and careers that exist (Woods-Townsend et al., 2015).

Interaction with scientist in this context of study allowed students to alter their prototypical images of scientists (Hannover & Kessels, 2004) and consequently, narrow the gap between perceived and actual images of scientists as indicated in the findings of reflective journals by the students. In addition, scientist played her integration function to show solidarity to students might also alter the prototypical image of students in term of socioemotional area of interaction. Deconstructing prototypical image of scientists and their work (Rahm, 2007) by bringing students in contact with practicing scientists is essential for allowing students an insight into the world of science, and what it means to think scientifically and to work as a scientist (Brickhouse, Lowery, & Schultz, 2000; Chen & Cowie, 2013). As Finson (2002, p. 335) asserts, 'individuals who have negative perceptions of science or of scientists are unlikely to pursue science courses of study and, subsequently, enter a science/science-related career'. This has implications for students' decision-making with respect to science careers. If students develop and embed notions of scientists as normal people, then it is more likely that they will be more interested in pursuing a science career.

However, in decision function as reported in findings, there could be intimidation issue faced by students during STS interaction. This is because scientist, in this study, is usually regarded by students as knowledgeable expert who hold higher status than students (Kerr, Cunningham-Burley & Tutton, 2007). Thus, when scientist voiced her view or opinion, students tend to take her view or opinion into account during decision-making. Hsu (2018) stated that students are usually denied a chance to express their ideas and needs due to this issue. This could be addressed as one of the challenges exists in scientist-students interaction in this study.

The findings revealed that scientist played major role in control functions followed by orientation functions in neutral task area analysis. Scientist gave instruction to students during experimentations as control functions and delivered knowledge students through discourse, demonstration, questioning etc. as orientation functions. These reflected the roles of scientist as science procedural knowledge authority in this study (Peker & Dolan, 2012). These control and orientation functions serves as the scaffolding for students to acquire science knowledge and procedural skills in this study.

The findings from IPA also revealed the role of teacher in assisting scientist to deliver the information which is more comprehensible to students in this study. Students have difficulties to understand the information and science knowledge delivered by scientist due to complexity and jargon concepts of scientific language (Hsu, 2018) based on the data of reflective journals. It could be due to existing prior knowledge possessed by students was not enough for them to understand the science knowledge beyond the syllabus as prescribed in the STSC-PPbl. On the other hand, it could be the way that scientist transmit knowledge to students need to be improved and more appropriate. Past studies addressed the challenge for some scientists with lack the appropriate skills for effective science communication, or that they are not offered sufficient training opportunities in developing the communication skills needed (Hsu, 2018; Davies *et al*., 2012; Ecklund, James, & Lincoln, 2012; Royal Society, 2006). With the explicit support of teacher, this challenge can be overcome when scientist was transmitting knowledge to students as addressed by Hsu (2018). This portrayed teacher as science pedagogical authority during the interaction in STSC-PPbl in this study which undertook the “One Assist and Facilitate”. The existence of role of teacher in collaborative relationship with both scientist and students in this study benefited the role of scientist in facilitating the interaction and providing assistance, as well as the role of students for their optimal gains in science learning during this collaboration, which were not stressed in past studies (e.g. scientist-students partnership, scientist-teacher partnership etc.).

Researcher believes that, besides nature of task as described in this study, personality traits of participants in could affect the nature of interaction during problem-project based learning in this study. These two aspects could be the missing parts that need to be uncovered for interaction study in future. The personality traits of participants need to be studied by interrelating the person-perspective factors and the situation-perspective factors (Bowers, 1973; Epstein & O’Brien, 1985; Kenrick & Funder, 1988). Situation-perspective factors, or called external factor, in this study is the authentic research setting include biology research laboratory and the practising researchers around the participants. However, this study lacked the exploration on person-perspective factors of scientist, teacher, and students such as personality traits and temperaments. All these factors shall be explored prior to complete, thorough interaction study.

This study focused on interaction process and patterns between scientist, teacher and students during problem-project based learning in authentic setting, leaving a gap in the present study about scientist's, teacher's, and students' views on interactions, as well as how such interactions should be structured to allow maximum positive effect on students' science learning. These gaps could be filled as recommendations for future study.

Tension in learning for students: Good or Bad?

One of the socioemotional areas of interaction process analysis in this study is tension management of students. The findings revealed that students showed higher level of negative tension management functions based on structural exchange pattern analysis of qualitative data from participant observations. This finding further supported by the reflections from students in this study. Researcher would like to discuss the existence of negative tension managements functions of students as observed during interaction of STSC-PPbl in this study. There are some questions researcher would like to pose before the discussion: "Are negative tension managements of students something bad? Or good?", "How researcher perceive these negative tension managements of students?" and "How to deal with these negative tension managements of students as perceived by researcher" to begin the discussion.

The findings from this study indicated that the negative tension management by students could be the negative emotions such as stressful, boredom, nervous etc. aroused during the interaction, whether intentional or unintentional, in STSC-PPbl. It All these were viewed as negative tension management as perceived by Bales (1950) during interaction. Austin and Senese (2007) argued that all these emotions, either positive or negative, are influenced by the individual's personality which was not covered in this study. The emotions aroused by students influence the science learning process in both positive and negative ways (Kochanska, Murray, & Harlan, 2000). Past studies also stressed the crucial role of emotions in affecting social interaction as well as learning such as goal orientation, motivation, and self-concept (Dweck, 1986) as emerged from the thematic analysis of reflective journals of students in this study. The learning processes and outcomes during STSC-PPbl interaction were also influenced by emotions (Valiente, Swanson, & Eisenberg, 2012). Thus, researcher believes that how emotions of students influenced by STSC-PPbl in authentic context deserves in-depth clarification. Lastly, it should be discussed how the teaching and learning and the design of interactive strategies may be provided in a more emotionally-oriented way that could benefit students for science learning purposes.

However, in this study, researcher would like to argue that all these negative tension management functions showed by students from interaction perspective could be perceived as positive tension for science learning at certain extent from education perspective with facilitation and support of MKO in this study, which were both scientist and teacher. Even though not all the tensions of students were resolved, however there were some acts of scientist and teacher in positive tension management and positive integration functions in socioemotional areas had partly resolved this issue. As posited by Heffer and Willoughby (2017), strategic conversion of negative tension from interaction to positive tension for learning can improve the science learning that benefit students in this interaction during STSC-PPbl. Thus, this argument worth the attention of scientist and teacher in this collaborative relationship and could be one of the expansions of study in future for formulation of effective interactive strategies.

Methodology on analysis of tripartite interaction

In this study, the contribution was made by preparing a methodological approach STSC-PPbl in observing and analysing tripartite interaction in by adapting the methods established by few past studies (Brown and Spang, 2008; Bales, 1950; Fahy, 2001). The data analysis methods utilised by researcher in this study was produced by blending major qualitative data analyses and visualization of interaction pattern between three parties of participants through minor quantification of qualitative data. This data analysis method had assisted researcher to generate a general figure on interaction pattern between scientist, teacher, and students during the collaboration as a "structural scaffold" of viewpoint, followed by in-depth explanations of each interaction patterns provided by qualitative data analyses and exploration. In short, such method provided synergistical understanding of interaction complexity from both structural and elements perspectives, giving a clearer picture to guide the researcher to understand the nature of interaction. In this section, how all the selected methodologies proposed in past studies by few researchers contributed to the establishment of each part of data analysis method in this study would be discussed in further. On the other hand, other limitations of this methodology would also be discussed and acknowledged based on the methodological practice of researcher in this study.

Observational research of interaction between scientist, teacher and students undoubtedly reveal certain extent of complexity. The complexity of this interaction means that the interactions happened is not in a 'confined' setting, i.e. the direction of interactions could vary and spontaneous. This is because human interaction is a dynamic process that unfolds in time (Gnisci, Bakeman & Quera, 2008). Thus, researcher realized that the picturing the interaction between multiple parties would not be easy.

As for data analysis of research questions in this study, there were three levels of data analysis: preparatory, macro, and micro-level analysis. Brown and Spang's (2008) methodology served as the reference for overall design and preparatory phase analytical approach in this study. They used the method to explore the language practice that emerged as a teacher taught a lesson designed to promote science literacy development for traditionally underrepresented students, which was then used by Jaipal (2010) to perform discourse analysis to understand the meaning-making in science classroom. This ethnographic study proposed that there are three systematic stages of data analysis which was adopted by researcher starting from organising the observational raw data to systematic analysis of coded data to generate overall themes and patterns of interaction as insights in whole produced in this study (Brown & Spang, 2008; Jaipal, 2010). Even though they used this method to analyse the discourse in science classroom, which the interaction were more structured as compared to the tripartite interaction in this study (mainly focus on discourse and linguistic analysis in science learning), however this method showed the structured organisation of data to help researcher gain general viewpoint (macro and micro level) of interaction pattern. In phase one, researcher adapted the data unit organisation notion proposed by Brown and Spang (2008). Researcher realised that the complexity of tripartite interaction in this study with multiple types of interactions such as conversation, behaviours, emotions, reflection, and scaffolding, as each of the modes could be intermingled with each other. Thus, the organisation of raw data to data unit for further analysis requires researcher to define what are the aspects to look and focus. Besides that, as this interaction adopted unstructured collaboration approach, participants in this study could interact with other participants freely and there is no fixed schedule of activity planning with possible unpredictable events (such as accidents). This condition increased the level of complexity of interaction due to its lack of structuredness, even though this could provide insights on nature of collaboration and interaction with little interference. In this study, researcher organized the observational data into four units based on the types of activities. Researcher put students' science learning as the focus among the participants in this study to explore the role of scientist and teacher in interacting with students. By organizing the observational data based on types of activities, one data unit constitutes the observation of events confined in an activity which might involve single or few days of engagements. Such characteristic enabled researcher to see the changes of practice (any improvement or not) by students for prolonged engagement.

Macro-level analysis, as the extension of preparatory analysis mentioned above, aimed to provide the macro-level overview of preliminary emergence of interaction pattern which shared the common goal as postulated by selected past studies (Brown & Spang, 2008; Jaipal, 2010). Therefore, researcher performed primary analysis named 'qualitative categorical analysis' in this study. Researcher defined qualitative categorical analysis as the rigorous interpretation based on open coding of each excerpt extracted from data unit with respect to each category. In this study, there are three categories of analysis namely scientist, teacher and students who played their functions in interactions during collaboration. The outcome of this analysis produced three "roles" associated with the functions of participants during the event of interaction. Also, researcher claimed that additional analysis could be performed if researcher would like to gain more insights from observational data from other perspectives. Thus, researcher suggests the generation of codes for learning outcomes, learning domains (cognitive, psychomotor, and affective) and multi-linkage mode of interaction for future study.

Micro-level analysis aimed to provide the micro-level overview for researcher to understand the nature of interaction of STSC-PPbl in this study. By using the three-stage "analytical scaffold" adapted from Brown and Spang (2008) and Jaipal (2010), researcher needed to add the perspectives that he wanted to use as the "lens" to meaningfully interpret the data to generate a detailed and thorough description of interaction pattern in this study. In this study, researcher incorporated three perspectives of micro-level analysis: (1) interaction elements and (2) structural exchange pattern from Bales (1950) and Fahy (2001) respectively

Bales's (1950) interaction process analysis model served as the foundation for first micro-level analysis of observational data which is interaction elements and interlocking relationship analysis. He proposed two analysis areas with observational behavioural indicators: tasks areas (neutral) and socioemotional areas (positive or negative). Then these analysis areas were coupled with six subareas namely orientation, control, evaluation, decision, tension management and integration. By using these two notions, researcher identified the role of each participant in interaction from task and emotion-oriented perspectives with emerging pattern of interaction along the process of data analysis. Researcher asserted the necessity of setting a participant or party as focus of interaction study to understand how the science learning was shaped during the collaboration. In this study, 'students' was the focus of the interaction and researcher explore the role, from both tasks and socioemotional perspectives, of scientist and teacher in affecting students' science learning through multipartite interaction. Also, researcher aimed to look for the change of more dependent to independent and self-directed learner characteristic portrayed by students through prolonged engagement of science learning with scientist and teacher. Therefore, researcher created another analysis area termed "independent task area" to protrude this significant characteristic to be observed and analysed by researcher.

Fahy's (2001) development of Transcript Analysis Tool (TAT) for studying patterns of interaction in computer conference transcript serve as the foundation of establishment of data analytical procedure for second micro-level analysis which is structural exchange pattern analysis. In TAT developed, there were two elements to analyse the interaction: (1) mode of interaction and (2) structural exchange pattern. These two elements could provide a more comprehensive view of pattern of interaction among the participants. Researcher adapted the method of structural exchange pattern analysis to quantification of qualitative data generated to visualise the pattern of interaction of STSC-PPbl due to the complexity revealed in this study. Fahy (2001) stated participants in that study did not choose alternate activity to replace the course conferencing requirement, thus all participants were members of the online network. This provided the research context with higher structuredness as compared to the unstructured collaborative interaction in this study. The research context in this study was characterised with unpredictability and lack of structuredness in collaboration and interaction among participants, even though researcher claimed that there was little planning for this collaboration before the research began. This SEP intended to quantify the data of first micro-level analysis on patterns of interaction by visualising density, intensities and ratios of modes of interaction and various interaction functions.

Researcher endeavored to picture ‘degree of involvement’ of each participant in this interaction as indication before proceeding to the exploration of such interaction in shaping the science learning of students. However, researcher shared the common understanding with Fahy (2001) that every single interaction is unique, and context based. Comparison should be made between groups of similar or same size with similar context and nature of task to provide more reliable description of interaction.

In sum, the findings of macro and three micro-level analysis could be integrated into a visual representation as utilised in this study as a reference or guide for researcher to understand the present collaboration, as well as for formulation of more effective collaboration in future. Such blending of major qualitative followed by quantification of qualitative data approach aimed to obtain a detailed and deep comprehension of the interaction studies, formulating descriptions, possible explanations, and hypotheses.

Anyhow, there might be possible limitations in this analytical procedure established. There could be some important real-world matters may be overlooked when rigorous experimental methods were applied to study this tripartite interaction (Gnisci, Bakeman & Quera, 2008). It could be this study maybe based on a too narrowly constructed a view of reality, on one hand, or based on too abstract a construction of the world without sufficient empirical grounding, on the other (Gnisci, et al., 2008). Besides that, as mentioned, the person-perspective factors of participants such as personality traits and temperament shall also be included prior to this interaction study methodology. To improve the analytical procedure adopted in this study, such considerations could be considered as recommendation for future study.

According to Bales' interaction process analysis, such analysis focuses on the nature of interaction takes place in a small group of people. According to the theoretical framework as depicted by Bales (1950), the cognitive, affective, and conative aspects of interaction process analysis hardly to be explored in-depth. Thus, researcher suggested that this could be served as the recommendation for future study through integration of other data collection methods.

One of the criticisms on Balesian IPA (1950) is the sequential context reflected in the categories (Heritage, 1984; Perakayla, 2004). This quantitative research method on social interactions has been criticized by qualitative researchers on failing to take the sequential context into the consideration on interactional analysis, that is, what happened just before and immediately after the act that is being considered (Heritage, 1984; Perakayla, 2004). Bales (1950) argued that IPA could take the context into account if the classification is uncertain of dilemmatic (Perakayla, 2004). In this study, researcher attempted to use Balesian IPA (1950) in more "qualitative" manner. It means that Balesian IPA (1950) served as the lens to understand the meanings constructed by scientist, teacher, and students during the interaction in PPbl in authentic research setting. Even though there were six predetermined themes were listed out by Bales (1950), however researcher stayed open to create *ad hoc* themes, i.e. the additional and emerged theme based on the participant observation notes and reflective journals in this study which attempted to reflect what scientist, teacher and students experiences to give a wholesome picture of interaction in this study. Gnisci, et al. (2008) argued that researcher who adopted Balesian IPA, which is a quantitative approach, to study interactions is less likely to change or modify the existing categories in IPA. In this study, researcher took Balesian IPA (1950) as the ground framework to categorise the interaction between scientist, teacher, and students in this study, but surprisingly emerged theme *independency* is found to complete the framework of this analysis. The emerged theme *independency* is one of the important "indicators" to know whether students has achieved the stage of independent learning during the collaboration.

Balesian IPA (1950) categorised the interactions by quantitative approach was argued by failing to consider what people feel, how people organise conversation, and how people perceive and categorise events in their speech (Gnisci, Bakeman and Quera, 2008). In this study, researcher attempted to "reverse" the method as adopted by Bales (1950). Researcher first used the Balesian IPA (1950) themes of interaction elements to explore the events of each activities in-depth by fitting them into according to the characteristics of each theme. This allowed researcher to have deeper understanding on how scientist, teacher, or students organise and orient in the events of collaboration. In this qualitative study, researcher wished to improve this very early category systems to yield meaningful results rather than mere descriptive data analysis as advocated by quantitative studies. After the proper organisation of data through qualitative approach, researcher then used SEP to picture the interaction through quantification of qualitative data (codes). In short, the sequence of analysis in this study is 'qualitative' first followed by simple 'quantitative'. Blending qualitative and quantitative analyses into observing interactions could serves as the recommendation for future study for multiple research approaches that can advance the knowledge of interaction in science education.

5.5 Research Implication

This research study reflected some implications on methodology, theoretical and practicality of STSC-PPbl in authentic research setting in science education.

Methodological Reflection

One interesting part in the research methodology used in this study is the production of systematic and comprehensive analytical framework to visualise the complexity of interaction from major qualitative coupled with little quantitative data for structural pattern. The study on multipartite interactions in this study is complex and uneasy. Therefore, it is apt to adapt a methodological analysis framework to organise and interpret the observational data supported with reflection from students to a meaningful description of interaction pattern which can help researcher to understand the nature of interaction of STSC-PPbl.

The study of interaction in this research was rooted from two perspectives which are (1) structural pattern and (2) interaction elements. The analytical frameworks used to explore the interaction was produced and adapted from selected and rigorous review of few research methodologies proposed by Brown and Spang (2008), Bales (1950) and Fahy (2001). The analytical framework produced from this study maximally extract and the qualitative data from the primary data sources, systematically codes the data, organised into a visualised pattern of interaction and assigned the meaning to various modes of interaction from various perspectives. This methodology could be applicable to other interaction study which involves more than two or three parties.

From structural exchange pattern analysis perspective, researcher adapted the methodology from Fahy (2001) to visualise the interaction pattern of scientist, teacher and students. In this methodology, besides showing interaction elements, researcher also showing the direction of interaction such as bipartite or tripartite interaction between participants (scientist, teacher, and students). This methodology could be applicable to other interaction study to gain a general viewpoint of the structure of interaction, as well as offer recommendation to improve the interaction based on findings on structural exchange pattern analysis.

Besides the application of this analytical procedure to study the tripartite interaction in this study, this method could be potentially applied to study the interaction process of other settings, or even more complex interaction which involved more than three parties with suitable adaptation and continuous improvement. Another contribution from the methodological perspective in this study is the integration of reflective practice by participants into data collection of interaction process analysis in this study.

Theoretical Implication

There were number of studies have examined various topics related to scientist-teacher-students (STS) partnership. Fadzil et al. (2019) investigated perception of students on STS partnership found that this tripartite collaboration benefited students through enrichment of learning experience, acquisition of procedural skills, as well as exploration on emerging topics and career opportunities in science. Peker and Dolan (2012) used social semiotic frameworks (rooted from Vygotsky's theory and developed by Lemke (1990)) to focus on conversation, which function as visual and linguistic resources, between experts (scientist and teacher) and novice (students) to investigate how students make meaning throughout the verbal interaction with experts. In other words, students experience the verbal interaction with scientist and teacher would make meaning of their acts. With that, researcher argued that alternative theoretical perspective could be used to explore the content and dynamic of interaction which as science learning in STS partnership is inseparable with social interaction by taking account not only verbal interaction (conversation), but the situational context such as authentic research environments, social context such as variety of scientific cultures due to different types of scientific activities and physical context such as pedagogical activity designs in STS partnership. With all these contexts taken into accounts, the wholesome exploration and understanding on how STS interaction (physically or verbally) could be meaningful. From this perspective researcher also argued that each of the STS interactions is unique and not replicable at different contexts, or context-dependent state. The different pedagogical designs and situations of STS partnership would possibly result in different perceptions of students.

Burgin et al. (2012) reported appreciable variance in students' experiences and outcomes associated with scientist-students apprenticeships programme in terms of collaboration, epistemic involvement and understanding of the significance of research results using cognitive apprenticeship (similar theoretical perspective with this study). The findings from the interviews also revealed that the supports given by the mentor (scientist) looked discontinuous, i.e. larger amount of mentor support at the beginning than students did at the end or low level of mentor support. Researcher argued that even though the perspectives on ideal level of mentor supports could vary depends on the needs of learners (students), however the form of mentor supports given to the students needs to be comprehended from the interaction perspectives as social interactions promote learning (Vygotsky,1978). It means that mentor support can be in variety of forms, such as physical, verbal, or socioemotional interactions. Nonetheless, low level of collaboration was rated by some students during the apprenticeship programme due to the completion of projects seemingly 'isolated' from one another, i.e. lack of rapport or intragroup support between the scientist and students.

Thus, this study adds to the literature by applying situated cognition theory and Vygotsky's social constructivism as theoretical lens to explore and explain the dynamic, complexity and intricacies of tripartite interaction between scientist, teacher, and students in this study. Situation cognition theory provided the 'context' for this study which posited that science learning and knowledge situated at authentic learning environment, in this case, natural environment and research laboratory bound to actual scientific culture context, i.e working together with scientist in the form of scientist-teacher-students collaboration. Meanwhile, Vygotsky's social constructivism stressed the vitality of social interaction in science learning in this study. The dynamic scientist-teacher-students interactions process mediate the science learning and knowledge acquisitions of students through collaboration with more knowledgeable others (MKO), in this study, scientist and teacher. By situating students to work with both scientist and science teacher in authentic research context, the detailed analysis of interaction dynamics could shed light on what kinds of interaction functions, either physically, verbally, or emotionally, could affect the students' science learning process throughout the study. The findings of this study also revealed how students act or react with the effect from the authentic research environment (research laboratory and instrumentation, scientific working culture in this context etc.)

The findings from neutral task area suggested the emergence of interrelationship between two subareas ‘control’ and ‘independency’ supported the concept of “Zone of Proximal Development” as mentioned in Vygotsky’s social constructivism. The ‘control’ functions played by scientist and/or teacher as more knowledgeable others (MKO) in directing students in task execution at higher level of supervised condition can directly or indirectly foster the ‘independency’, which students can perform task execution independently from behavioral or cognitive perspective with little or no supervised condition.

By using the three-stage analytical procedures which was modelled from Balesian Interaction Process Analysis, besides looking at neutral task areas functions, the findings of the study explicitly address the attention given to the socioemotional area of interaction. Vygotsky posited that cultural context (in this study, scientific culture in authentic research context) could also lead to the understanding of social emotions between learners (students) and experts (scientist and teacher) as well as how it affects the science learning of students in this study. This advances the understanding of interaction, contributing to more wholesome exploration in this study.

Moreover, the differentiated functions of teacher reported in this study during the interaction advances the existing model of or scientist-students apprenticeship and STS in past studies to support students’ science learning either at neutral task or socioemotional area. Teacher function as facilitator in ‘one assist and facilitate’ could create the intragroup support for this partnership, bridging the collaboration between scientist and students as issued (Burgin et al., 2012).

Practicality of STSC-PPbl

STSC-PPbl is one of the significant endeavours to bridge the gap between school and industry, tertiary education or research institute to collaborate in improving existing science education in our country which transform the 'problems' to be solved by students to a 'project' which bring a workable outcome in three-phase implementations: (1) crafting problems, (2) practical works and experimentation and (3) communication of findings. This pedagogical activity is considered a considerable approach for science education policymakers to encourage industry-school partnership to expose students with real-world context with the aim of fostering science talents for sustainable socioeconomic development (Peker & Dolan, 2012; Rahm, 2016).

STSC-PPbl has features that could benefit science educators, students and even science education policymakers and some institutes. The goal of this collaboration is to expose students with 'authentic science' in supplementing the existing science curriculum and traditional science learning as argued by Rudolph (2019). The following parts will explain the practicality of each phase followed by some suggestions recommended by researchers for improvement in future study.

In phase one, teacher and students worked together to formulate a problem prior to project before collaborating with scientist. The general flow of phase one involved exposure to real-world issues, narrowing of scope of study, formulation of problem statement and lastly proposal of possible, workable solutions for project execution in next phase. All these components of phase one are the gist of problem-based learning as perceived by researcher in this study. All these characteristics of phase one were in line with idea of problem-based learning with Yew and Goh (2016) where the problem in this study was generated by students themselves (*student-*

generated issues) rather than the scenario or problem was provided by teacher and students directed their own learning and study during the problem formulation (*self-directed study*). Thus, researcher argued that more study needs to be done on the *student-generated issue* and *self-directed* study at this stage which contribute to the quality of the problem. Based on the findings from reflective journals written by students, students spent time on self-directed study, preparation and literature reviews to increase the level of understanding on the problem they formulated. Yew and Goh (2016) argued that the quality of a problem would influence group functioning which in turn influence allocation of time on individual study. The increase in time spent on individual study, the higher the leading academic achievement. During the evaluation of problem, the model of protocol of problem-based learning developed by Mohd Yusof *et al.* (2012). Besides that, researcher adopted combination of mind-mapping and justification through rigorous background search to help students to narrow the ideas and lead to decision-making on problem selection prior to project in this study. However, to improve the epistemic learning of this phase, researcher hoped to involve scientist in problem formulation phase.

In phase two, both teacher and students worked with scientist to do experiments and research. These tripartite collaboration and interaction benefited all the participants in this study. Both teacher and students brought the problem formulated in phase one to seek potential collaborator, in this case research institute, to convert problem into project in this study. This collaboration achieved the aim to promote industry-school partnership that encourage collaboration between school and research institute for promotion of authentic science learning and improve the existing science education, this creating a new science education paradigm in future to be explored. As argued by Vygotsky's social constructivism, the co-construction of knowledge between scientist, teacher and students occur through the social interaction between participants. Scientist could take this opportunity to promote science communication to students and transfer the skills and knowledge through project-based learning process as discussed earlier. Students gained knowledge and experience to collaborate with scientist to work on a project for college and work readiness. Meanwhile, from science educator's perspective, STSC-PPbl could also contribute to the professional development of science teacher by experiencing the scientific investigation in authentic context together with scientist and teacher in this study. Teacher gained fresh perspective of science during the interaction STSC-PPbl which could be used during the science knowledge transmission during the science learning in classroom. On the other hand, the role of teacher in facilitating the interaction between scientist and students as well as optimum science learning of students could be viewed as a new pedagogical content knowledge and skills to be equipped by science teacher and worth more exploration. From teacher professional development perspective, such involvement increase the quality and competency of science teacher due to the arguments on their deficiency in authentic science investigation experience that in turn affect how science is taught in school science (Alan, Zengin, and Kececi, 2019; Fadzil and Saat, 2013). From researcher's point of view, it could promote a new identity of science teacher to become "teacher as scientist". This identity reveals both pedagogical and research competency of science teacher to educate students with significant improvements.

In phase three, students and teacher work on data analysis and communication of findings to public. Even though this phase was not included in this study, researcher believed that this phase supports the call of the implementation of phase one and two to promote science communications between students and public to showcase their learning outcomes.

From policymaker perspective, the STSC-PPbl in this study was one of the approaches to promote industry-school partnership in science education. It was evident that there was a challenge to schedule the collaboration between scientist, teacher and students in this study in term of time factor. This was because each participant has their own commitments in school and research institute. The findings from this study revealed that students were benefited from STSC-PPbl in term of cognitive, psychomotor domains. Thus, science education policymakers could discuss this issue with all the stakeholders to schedule this meaningful collaboration.

In sum, researcher suggested to increase the intensity of scientist-teacher-students interaction in these three phases based on the findings from interaction process analysis. This suggestion is to increase the epistemic learning aspects of STSC-PPbl as argued by Burgin et al. (2012). The epistemic learning of STSC-PPbl requires students to go through the process of conducting scientific investigation and science process skills as practised by scientist or researcher in real-world context. Such epistemic learning of STSC-PPbl proposed is not similar with the problem or project-based learning that usually involve only teacher and students in school learning context.

5.6 Recommendation for Further Study

Based on the experience in conducting this research, recommendations are made as follows:

(1) *Three-phase problem-project design of Scientist-Teacher-Students Collaboration in Research Apprenticeships*

In present study, the focus was given to study the interaction between scientist, teacher and students in practical works phase. The findings of this study illustrated the potential of this collaboration to help students learn science in affective domains which drive the development of cognitive and psychomotor knowledge and skills, as well as promote the lifelong learning concept in science education. However, based on the findings of interaction process in this study, the pedagogical approach tended to be more direct-instructional. Researcher believes that students need to be given more exposure on this collaboration with a more complete problem-project based design, starting from problem-project based design (Phase One), practical works and experiments (Phase Two) and communication of findings with scientist (Phase Three). Past studies suggested that the ideal apprenticeship context is one in which the student takes an active role in developing research questions, the designing procedures and interpreting results in developing comprehensive view of nature of science as epistemic involvement of students (Barab and Hay 2001; Bell et al. 2003; Ritchie and Rigano 1996; Ryder and Leach 1999).

(2) Methodological Improvement on Three-Stage Tripartite Interaction Process Analysis

In this study, three-stage tripartite interaction process analytical procedures established from adaptation from Brown and Spang (2008), Bales (1949), Fahy (2001) and Jaipal (2009, 2010) was applied to study the interaction process of scientist-teacher-students collaboration in problem-project based learning in authentic research setting with recognised limitations which centred on the narrowly constructed of view of reality or important real-world matters that may be overlooked. To improve the feasibility and workability of this analytical procedure to provide more thorough description of tripartite interaction, the established method could be applied to more interactions in authentic research setting to produce a more comprehensive analytical framework.

(3) In-depth exploration on the learning outcomes associated with participation by students

Researcher believes that students were the 'main character' expected to be benefited from STSC-PPbl in this study. By only looking at the interaction study of STSC-PPbl does not mean that meaningful science learning by students took place in this study. Thus, thematic analysis could be done to analyse the reflective journals to have in-depth exploration learning outcomes associated with participation in STSC-PPbl in future.

(4) Perception Study of Scientist, Teacher and Students

Another important study that need to be carried out in future research is the perception study of participants in scientist-teacher-students collaboration in problem-project based learning in authentic research. Researcher believes that it is crucial to explore how scientist, teacher, and students organize and interpret their sensory inputs, or so called what they see and hear (or termed 'reality'). The study on perceptions are important because scientist, teacher and students' interactions, which are highly characterised by various intermingling modes of interactions such as emotions, behaviours, scaffoldings, conversation and reflections, are based on their perception of what reality is. Therefore, participants; perceptions of this collaboration in authentic research setting become the basis on which they behave during the interaction. Also, researcher recognised the individuals' perceptions can be vastly different. These differences can be due to various life experiences, levels of education, and personal factors such as attitudes, interests, and motives. Therefore, by definition, individuals' perceptions are neither right nor wrong.

Of course, to what extent this collaboration was successful at engaging students in the meaning-making process is a significant aspect to be considered. Also, it is crucial to include scientist and teacher's perception in formulating more effective collaboration in engaging students' science learning. Thus, as recommendation for further study, it requires consideration of data sources from scientist's, teacher's and students' perspectives in addition to the interaction patterns and elements in this collaboration.

(5) Using Nominal Group Technique to evaluate and improve the interaction

The Nominal Group Technique (NGT) is an evaluative approach allows that a group of participants generate ideas and thoughts through questioning whilst maintaining anonymity throughout the process simultaneously (Olsen, 2019). The researcher might face difficult decisions in improving the interactive strategies between scientist, teacher and students for optimum science learning in future and the process of interaction process analysis. Researcher suggested a group of participants for NGT could be the stakeholders of science education including school administrators, science teachers, scientists and students in providing suggestions to improve the existing interaction in this study. Idea generation during discussion and problem-solving are combined in this structured group process, which encourages and enhances the participation of group members during NGT. This could be further done in future study after several interactions' studies and interaction process analyses.

(6) Development of Interactive Model for STSC-PPbl

Based on the findings of in this study and the reflections made by students during STSC-PPbl, a model of training for face-to-face interactions with between scientist, teacher and school-aged students could be designed, which could maximise the benefits of such interactions for all groups. The roles of scientist and teacher from Bales's (1950) interaction process analysis perspectives could be improved based on the suggestions made after investigating the perspectives of all participants in this study. The emerging challenges for students during science learning during STSC-PPbl could be considered and overcome during the design of interactive model. The interaction model designed should also be responsive to the students' needs, and both scientists and teacher should be offered help in identifying ways in which their work could be contextualised for the students, providing the main aims and rationale of their work in a way that points out its significance but is also simple enough for students to understand.

5.7 Summary

In summary, several conclusions were drawn from this study from interaction process analysis and structural exchange pattern perspective. Scientist, teacher, and students interacted with each other in expected mode of interaction based on the findings of structural exchange pattern analysis. In socioemotional areas, students showed negative tension managements that worth attention and discussion by researcher for optimum science learning in future. The roles of scientist and teacher during interactions were discussed based on the findings on interaction process analysis.

Researcher discussed some issues related to the findings from interaction process analysis and reflections from students such as viewpoints on structure of interaction during STSC-PPbl, affective engagements of students, tension of learning from students during interaction as well as methodological reflection on the interaction process analysis adapted from Bales (1950) and Fahy (2001) in this study. The research implications on methodology and practicality of STSC-PPbl were also discussed. There are several recommendations made by researcher for future study.

REFERENCES

Abrahams, I., Reiss, M. J., & Sharpe, R. M. (2013). The assessment of practical work in school science. *Studies in Science Education*, *49*(2), 209-251.

Academy of Sciences (2017). *Science outlook report*. Kuala Lumpur, Malaysia: Academy of Sciences Malaysia.

Adams, C. T., & Hemingway, C. A. (2014). What does online mentorship of secondary science students look like? *BioScience*, *64*, 1042-1051.

Alan, B., Zengin, F. K., & Kececi, G. (2019). Using STEM applications for supporting integrated teaching knowledge of pre-service science teachers. *Journal of Baltic Science Education*, *18*(2), 158-170.

Austin, T., & Senese, J. (2007). Self-study in school teaching: Teacher's perspectives. InJ. Loughran (Ed.), *International handbook of self-study of teaching and teacher education practices*, 1231−1258, Dordrecht: Springer.

Australian Education Council. (2018). *Optimising STEM Industry-School Partnerships: Inspiring Australians Next Generation*. A Final Report of STEM Partnership Forum, Australia.

Babbie, E. (1990). *Survey Research Methods*. 2nd Edition, Wadsworth, Belmont.

Bailin, S., Case, R., Coombs, J. R., & Daniels, L. B. (1999). Conceptualizing critical thinking. *Journal of Curriculum Studies, 31*(3), 285–302.

Bales, R. F. (1950). *Interaction process analysis: a method for the study of small groups*. Cambridge, Mass.: Addison-Wesley Press.

Bales, R. F. (1953). The equilibrium problem in small groups. In T. Parsons, R. F. Bales, & E. A. Shils (Eds.), *Working papers in the theory of action.* 111–167. Glencoe, IL: Free Press.

Bales, R. F., & Slater, P. E. (1956). Role differentiation in small decision-making groups. In T. Parsons & R. F. Bales (Eds.), *Family-socialization and interaction process*. 259–306. London: Routledge.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall.

Barab, S. A., & Hay, K. E. (2001). Doing science at the elbows of experts: Issue related to the Science Apprenticeship Camp. *Journal of Research in Science Teaching, 38*, 70–102.

Barman, C. (1999). Students' views about scientists and school science: Engaging K-8 teachers in a national study. *Journal of Science Teacher Education, 10*(1), 43–54.

Barron, B., & Darling-Hammond, L. (2008). Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning. *Powerful Learning: What We Know About Teaching for Understanding*. San Francisco, CA: Jossey-Bass.

Bell, R. L., Blair, L. M., Crawford, B. A., & Lederman, N. G. (2003). Just do it? Impact of a science apprenticeship program on high school students' understanding of the nature of science and scientific inquiry. *Journal of Research in Science Teaching*, *40*(5), 487–509.

Besley, C. J., & Tanner, H. A. (2011). What science communication scholars think about training scientists to communicate. *Science Communication*, *33*(2), 239–263.

Bleicher, R. (1996). High school students learning science in university research laboratories. *Journal of Research in Science Teaching*, *33*, 1115–1133.

Borresen, C. R. (1990). Success in introductory statistics with small groups. *College Teaching, 38*,26–28.

Bowers, K. (1973). Situationism in psychology: an analysis and a critique. *Psychological Review*, *80*, 307–336. doi:10.1037/h0035592.

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code development*. Sage Publications, Inc.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*, 77-101.

Brickhouse, N. W., Lowery, P., & Schultz, K. (2000). What kind of a girl does science? The construction of school science identities. *Journal of Research in Science Teaching*, *37*(5), 441–458.

Brown, B.A., & Spang, E. (2008). Double talk: Synthesising everyday and science language in the classroom. *Science Education*, *92*, 708-732.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher*, *18*(1), 32-42.

Burgin, S.R., Sadler, T.D., & Koroly, M.J. (2012). High School Students Participation in Scientific Research Apprenticeships: Variation in and Relationship amongs Students' Experience and Outcomes. *Research in Science Education*, *42*(3). 439-467. https://doi.org/10.1007/s11165-010-9205-2.

Carnevale, A. P., Smith, N., & Melton, M. (2011). *STEM: Science, technology, engineering, mathematics*. Georgetown University Center on Education and the Workforce: Washington, DC.

Ceker, E. & Ozdamli, F. (2016). Features and characteristics of problem-based learning. *Cypriot Journal of Educational Science*, *11*(4), 195-202.

Chambers, D.W. (1983). Stereotypic images of the scientist: The draw-a-scientist test. *Science Education*,*67*, 255–265.

Chen, Junjun & Cowie, Bronwen. (2013). Engaging Primary Students in Learning about New Zealand Birds: A socially relevant context. *International Journal of Science Education*, *35*, 1344-1366. 10.1080/09500693.2012.763194.

Childs, P.E., Hayes, S.M. & Dwyer, A.O. (2015). Chemistry and everyday life: Relating secondary school chemistry to the current and future lives of students. In *Relevant Chemistry Education: From Theory to Practice, 33-54*. Sense Publishers

Chin, C. (2019). *Interest in science continues to drop*. Online article published in TheStar. Retrieved from https://www.thestar.com.my/news/education/2019/03/17/interest-in-science-continues-to-drop/

Chinn, C. A., and Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*, 175–218.

Choudry, S., Bianchi, L., Chippindall, J., & Black, L. (2017). Scientist-teacher collaboration: exploring the nature of successful STEM placements in primary school. *Journal of Emergent Science*, *12*, 84-98.

Christidou, V. (2010). Greek students' images of scientific researchers. *Journal of Science Communication*,*9*(3), 1–12.

Christidou, V., & Kouvatas, A. (2013). Visual self-images of scientists and science in Greece. *Public Understanding of Science*, *22*(1), 91–109.

Cindy, E., & Hmelo, S. (2004). Problem-Based Learning: What and How Do Students Learn?. *Educational Psychology Review*, *16*(3), 237-240.

Claudio, L. (2001). Reaching out to the next generation of scientists. *Thought & Action*, *17*(1), 77-86.

Cobb, P. (1994). Where Is the Mind? Constructivist and Sociocultural Perspectives on Mathematical Development. *Educational Researcher*,*23*(7),13-20.

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. In E. Dubinsky, D. Mathews, & B. E. Reynolds (Eds.), *Readings in cooperative learning for undergraduate mathematics,* 135–156. Washington, DC: Mathematics Association of America.

Collins, A. (2006). Cognitive apprenticeship. In R. K. Sawyer (Ed.), T*he Cambridge handbook of the learning sciences*, 47-60. Cambridge: Cambridge University Press.

Condliffe, B., Visher, M. G., Bangser, M. R., Drohojowska, S., & Saco, L. (2016). *Project-based learning: A Literature Review*. MDRC.

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches (2nd ed.)*. Thousand Oaks, CA, US: Sage Publications, Inc.

Davies, A., Mbete, B., Fegan, G., Molyneux, S., & Kinyanjui, S. (2012). Seeing 'With my Own Eyes': Strengthening interactions between researches and schools. *IDS Bulletin, 43*(5), 61–67.

De Jong, O., & Talanquer, V. A. (2015). Why is it relevant to learn the big ideas in chemistry at school? In *Relevant Chemistry Education: From Theory to Practice,* 11-31. Sense Publishers.

Dees, R. L. (1991). The role of cooperative learning in increasing problem-solving ability in a college remedial course. *Journal for Research in Mathematics Education, 22*, 409–421.

Dewey, J. (1910/1933). *How we think: A restatement of the relation of Reflective thinking to the educative process.* Lexington, MA: Heath.

Dillenbourg, P. (1999). What do you mean by 'collaborative learning?' In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and Computational Approaches,* 1–19. Oxford: Elsevier.

Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1996). The evolution of research on collaborative learning. In E. Spada & P. Reiman (Eds.), *Learning in humans and machine: Towards an interdisciplinary learning science,* 189-211. Oxford: Elsevier.

Dillon, J. (2009). On scientific literacy and curriculum reform. *International Journal of Environmental & Science Education*, *4*, 201–213.

Dolan, E. L., & Grady, J. R. (2010). Recognizing students' scientific reasoning: A tool for categorizing complexity of reasoning during teaching by inquiry. *Journal of Science Teacher Education, 21*(1), 31–55. doi: 10.1007/s10972–009–9154–7.

Dweck, C. S. (1986). Motivational processes affecting learning. *American Psychologist, 41*,1040−1048.

Ecklund, E. H., James, S. A., & Lincoln, A. E. (2012). How academic biologists and physicists view science outreach. *PLoS ONE, 7*(5), 1–5, e36240.

Eggert, S., Ostermeyer, F., Hasselhorn, M., and Bögeholz,S. (2013). Socioscientific Decision Making in the Science Classroom: The Effect of Embedded Metacognitive Instructions on Students' Learning Outcomes. *Education Research International,* Article ID 309894.

Epstein S, O'Brien EJ. 1985 The person-situation debate in historical and current perspective. *Psychological Bulletin, 98*, 513–537. doi:10.1037/0033-2909.98.3.513.

Ergün, A. (2019). Identification of the interest of Turkish middle-school students in STEM careers: Gender and grade level differences. *Journal of Baltic Science Education, 18*(1), 90-104. doi.org/10.33225/jbse/19.18.90.

Erlingsson, C., and Brysiewicz, P. (2017). A hands-on guide to doing content analysis. *African Journal of Emergency Medicine*, *7*, 93–99.

Ertmer, P. A., & Simons, K. D. (2005). Scaffolding teachers' effort to implement problem-basd learning. *International Journal of Learning, 12*(4), 319-328

Eskola, A. (1961). *Social influence and power in two-person groups*. Turku: Westermarck Society.

Evans, C.A., Abrams, E.D., Rock, B.N., and Spencer, S.L. (2001) Student/Scientist partnerships: A teacher's guide to evaluating the critical components. *The American Biology Teacher, 63*(5), 318-323. DOI: 10.2307/4451118.

Fadzil, H. M., & Saat, R. M. (2017). Exploring students' acquisition of manipulative skills during science practical work. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(8), 4591-4607.

Fadzil, H.M., & Saat, R.M. (2013). Phenomenographic study of students' manipulative skills during transition from primary to secondary school. *Jurnal Teknologi, 63*(2), 71-75.

Fadzil, H.M., Saat, R,H. Awang, K., and Hasan Adli, D.H. (2019). Students' perception of learning stem-related subjects through scientist-teacher-student partnership (STSP). *Journal of Baltic Science Education, 18*(4). 537-548.

Fahy, P. J. (2001). Addressing some Common Problems in Transcript Analysis. *The International Review of Research in Open and Distributed Learning, 1*(2). https://doi.org/10.19173/irrodl.v1i2.321.

Fall, R. Webb, N., & Chudowsky, N. (1997). *Group discussion and large-scale language arts assessment: Effects on students' comprehension*. CSE Technical Report 445. Los Angeles, CRESST.

Falloon, G. (2013). Forging school–scientist partnerships: A case of easier said than done? *Journal of Science Education and Technology, 22*(6), 858-876.

Finson, K. D. (2002). Drawing a scientist: What we do and do not know after fifty years of drawings. *School Science and Mathematics, 102*(7), 335–345.

Friend, M. P., & Cook, L. (2000). Interactions: Collaboration skills for school professionals. New York: Longman.

Forcael, E., González, V., Orozco, F., Opazo, A., Suazo, Á., & Aránguiz, P. (2015). Application of Problem-Based Learning to Teaching the Critical Path Method. *Journal of Professional Issues In Engineering Education And Practice, 141*(3), 04014016. http://dx.doi.org/10.1061/(asce)ei.1943- 5541.0000236

Fuccia, D., Witteck, T., Markic, S., & Eilks, I. (2012). Trend in practical work in German science education. *Eurasia Journal of Mathematics, Science and Technology Education, 8*(1), 59-72.

Gibson, H., & Chase, C. (2002). Longitudinal impact of an inquiry-based science program on middle school students' attitudes toward science. *Science Education, 86*, 693–705.

Gilbert, J. K. (2006). On the nature of 'context' in chemical education. *International Journal of Science Education, 28*, 957–976.

Given, L. M. (2008). *The sage encyclopedia of qualitative research methods*. Thousand Oaks, CA: Sage.

Gnisci, Augusto & Bakeman, Roger & Quera, Vicenç. (2014). Blending qualitative and quantitative analyses in observing interaction: Misunderstandings, applications and proposals. *International Journal of Multiple Research Approaches, 2*, 15-30. 10.5172/mra.455.2.1.15.

Gorse, C.A., and Emmit, S. (2005). Group interaction research methods. *In:* Khosrowshahi, F. (Ed.), *21st Annual ARCOM Conference,* 7-9 September 2005, SOAS, University of London. Association of Researchers in Construction Management, *1*, 13-22.

Halim L., and Meerah T. S. M. (2016). Science education research and practice in Malaysia. In: Chiu M. H. (Eds.), *Science Education Research and Practice in Asia*. Springer, Singapore.

Hannover, B., & Kessels, U. (2004). Self-to-prototype matching as a strategy for making academic choices: Why high school students do not like math and science. *Learning and Instruction, 14*(1),51–67.

Heffer T, & Willoughby, T. (2017) A count of coping strategies: A longitudinal study investigating an alternative method to understanding coping and adjustment. *PLoS ONE*, *12*(10): e0186057. https://doi.org/10.1371/journal.pone.0186057

Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping: Part 1. Group versus individual problem solving. *American Journal of Physics, 60,* 627–636.

Hennessy, S. (1993). Situated Cognition and Cognitive Apprenticeship: Implications for Classroom Learning. *Studies in Science Education,22*. 10.1080/03057269308560019.

Hodson D. (2012) *Connections to Support Learning About Science. In: France B., Compton V. (eds) Bringing Communities Together*. Sense Publishers, Rotterdam

Hofstein, A., Eilks, I., & Bybee, R. (2011). Societal issues and their importance for contemporary science education: A pedagogical justification and the state of the art in Israel, Germany and the USA. *International Journal of Science and Mathematics Education, 9*, 1459–1483.

Holbrook, J. (1998). Operationalising scientific and technological literacy – a new approach to science teaching. *Science Education International, 9*, 13–18.

Houseal, A. K., Abd-El-Khalick, F., & Destefano, L. (2014). Impact of student-teacher-scientist partnership on students' and teachers' content knowledge, attitudes toward science and pedagogical practices. *Journal of Research in Science Teaching, 51*(1), 84-115.

Howell, J. M. (1972). The Host-State Consent for International Forces. *India Quarterly, 28*(1), 46–51. https://doi.org/10.1177/097492847202800103.

Hsu, P.L. (2018). High School Students' and Scientists' Experiential Description of Cogenerative Dialouges. *International Journal of Science and Mathematics Education, 17*(4) 657-677. https://doi.org/10.1007/s10763-017-9877-4.

Hsu, P.L., & Roth, W.M. (2010). From a sense of stereotypically foreign to belonging in a science community: Ways of Experiential Description About High School Students' Science Internship. *Research in Science Education, 40*(3) 291-311. https://doi.org/10.1007/s11165-009-9121-5

Hung, W. (2008). The 9-step problem design process for problem-based learning: Application of the 3C3R model. *Educational Research Review, 4*(2) 118-141.

Jaipal, K. (2010) Meaning making through multiple modalities in a biology classroom: A multimodal semiotics discourse analysis. *Science Education, 94*, 48–72.

Jaremus, F., Gore, J., Fray, L., & Prieto-Rodriguez, E. (2019). Senior secondary student participation in STEM: Beyond national statistics. *Mathematics Education Research Journal, 31*(2), 151-173.

Johnson, D.W., Johnson, R., Ortiz, A., & Stanne, M. (1991). Impact of positive goal and resource interdependence on achievement, interaction, and attitudes. *Journal of General Psychology, 118*, 341–347.

Johnson, D.W., Johnson, R., Stanne, M., & Garibaldi, A. (1990). Impact of group processing on achievement in cooperative groups. *Journal of Social Psychology, 130*, 507–516.

Johnston, Timothy. (2011). Roles And Responsibilities In Team Projects. *Journal of College Teaching & Learning (TLC),2*. 10.19030/tlc.v2i12.1894.

Jones, M. and Winne, P. (1992). *Adaptive Learning Environments: Foundations and Frontiers*. Springer-Verlag Berlin Heidelberg.

Keeler, C. M., & Steinhorst, R. K. (1994). Cooperative learning in statistics. *Teaching Statistics, 16,*81–84.

Kenrick D, Funder D. 1988 Profiting from controversy: lessons from the person-situation debate. *American Psychologist, 43*, 23–34. doi:10.1037/0003-066X.43.1.23.

Kerr, A., Cunningham-Burley, S., & Tutton, R. (2007). Shifting subject positions: experts and lay people in public dialogue. *Social Studies of Science, 37*(3), 385-411. https://doi.org/10.1177/0306312706068492.

Khattak, A. (2018). Solution Based Learning; Educating for Solutions. *Khyber Medical University Journal,9*.

Knox, K. L., Moynihan, J. A., & Markowitz, D. G. (2003). Evaluation of short-term impact of a high school summer science program on students' perceived knowledge and skills. *Journal of Science Education and Technology, 12*(4), 471–478.

Kochanska, G., Murray, K., & Harlan, E. T. (2000). Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology, 36*, 220−232.

Laal, M., & Ghodsi, S.M. (2012). Benefits of collaborative learning. *Procedia of Social and Behavioural Sciences, 31,* 486-490.

LaForce, M., Noble, E., & Blackwell, C. (2017). Problem-Based Learning (PBL) and Student Interest in STEM Careers: The Roles of Motivation and Ability Beliefs. *Education Sciences, 7*(4), 92. https://doi.org/10.3390/educsci7040092.

Larmer, J. (2014). *Project-based learning vs. problem based learning vs. X BL.* Retrieved from http://www.edutopia.org/blog/pbl-vs-pbl-vs-xbl-john-larmer

Laursen, S., Liston, C., Thiry, H., & Graf, J. (2007). What good is a scientist in the classroom? Participant outcomes and program design features for a short-duration science outreach intervention in K-12 classrooms. *CBE-Life Sciences Education, 6*, 49–64.

Lave, J., & Wenger, E. (1991) *Situated Learning Legitimate Peripheral Participation*. Cambridge Cambridge University Press.

Leder, Gilah. (1987). Teacher student interaction: A case study. *Educational Studies in Mathematics,18*, 255-271. 10.1007/BF00386198.

Lemke, J. L. (1990). Talking science: Language, learning, and values. Westport, CT: Ablex Publishing.

Manstead, A. S. R & Semin, G.R. (2001). Methodology in social psychology: Tools to test theories. In M. Hewstone & W. Stroebe (Eds.), *Introduction to social psychology. A European perspective*, 73–113. Oxford: Blackwell.

Martin, M.O., Mullis, I.V.S., Gonzelez, E.J., and Chrostowski, S.J. (2004). *TIMSS 2003 International Science Report*. Chestnut Hill, MA:TIMSS & PIRLS International Study Center.

Marjan Laal, Mozhgan Laal and Kermanshahi, Z. (2012). 21st Century Learning; Learning in Collaboration. Procedia - Social and Behavioral Sciences. 47. 1696-1701. 10.1016/j.sbspro.2012.06.885.

Masson, A.L., Klop, T., & Osseweijer, P. (2016). An analysis of the impact of student-scientist interaction in a technology design activity, using the expectancy-value model of achievement related choice. *International Journal of Technology and Design Education, 26*(1) 81-104. https://doi.org/10.1007/s10798-014-9296-6

Mastropieri, M. A., & Scruggs, T. E. (2004). *The inclusive classroom: Strategies for effective instruction* (2nd ed.). Columbus, OH: Prentice Hall.

McLoone, S., Lawlor, B., & Meehan, A. (2016). The Implementation and Evaluation of a Project-Oriented Problem-Based Learning Module in a First Year Engineering Programme. *Journal of Problem Based Learning in Higher Education, 4*(1), 71-80. http://dx.doi.org/http://dx.doi.org/10.5278/ojs.jpblhe.v0i0.1243.

Mercer, N. (1996). The quality of talk in children's collaborative activity in the classroom. *Learning and Instruction, 6*(4), 359–377.

Mergendoller, J. R., & Thomas, J. W. (2005). *Managing Project-Based Learning Principles from the field.* Retrieved from http://www.bie.org/images/uploads/general/f6d0b4a5d9e37c0e0317acb7942d27b0.pdf

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook.* SAGE Publications, Inc

Ministry of Education (2018). *Quick Facts: Malaysia Educational Statistics*. Educational Planning and Research Division. Retrieved from https://www.moe.gov.my/penerbitan/1587-quick-facts-2018-malaysia-educational-statistics-1/file

Mohd Yusof, K., & Helmi, S., Jamaludin, M., & Harun, N.F.. (2012). Cooperative Problem-based Learning (CPBL): Framework for Integrating Cooperative Learning and Problem-based Learning. *Procedia - Social and Behavioural Sciences, 56*. 223–232. 10.1016/j.sbspro.2012.09.649.

Moll, L. C. (2001) Through the mediation of others: Vygotskian research on teaching. In: Richardson, V. (eds). *Handbook of research on teaching* (4th ed.). Washington, DC: American Educational Research Association. 111-129.

Mortimer, E., & Scott, P. (2003). *Meaning making in secondary science classrooms*. Open University Press; Maidenhead, UK.

Mullis, I.V.S., and Jenkins, L.B. (1988). *The science report card: Trends and achievement based on the 1986 national assessment*. Princeton, NJ: Educational Testing Service.

Mumba, F., Banda, A., & Chabalengula, V.M. (2015). Chemistry Teachers' Perceived Benefits and Challenges of Inquiry-based Instruction in Inclusive Chemistry Classroom. *Science Education International,* 26 (2), 180-194.

Mumba, F., Mejia, W. F., Chabalengula, V. M., & Mbewe, S. (2010). Resident scientists' instructional practices and their perceived benefits and difficulties of inquiry in schools. *Journal of Baltic Science Education, 9*, 187–195.

National Center for Education Statistics (2004). *International Outcome of Learning in Mathematics Literacy and Problem Solving: PISA 2003 Results from the U.S. Perspective*. Washington, DC: National Center for Education Statistics.

National Clearinghouse for Comprehensive School Reform. (2004). *Putting the pieces together: Lesson from the comprehensive school reform*. Washington, DC.

National Research Council. (2000). *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*. Washington, DC: The National Academies Press. https://doi.org/10.17226/9596.

Newmann, F. M., & Wehlage, G. G. (1995). *Successful school restructuring: A report to the public and educators*. American Federation of Teachers.

Ng, S.B. (2014). *Malaysian School Science Education: Challenges and the Way Forward*. Curriculum Development Division, Ministry of Education, Malaysia.

Ng, W., & Fergusson, J. (2019). Technology-Enhanced Science Partnership Initiative: Impact on Secondary Science Teacher. *Research in Science Education, 49*(1), 219-242 https://doi.org/10.1007/s11165-017-9619-1.

Norwood, K. S. (1995). The effects of the use of problem solving and cooperative learning on the mathematics achievement of underprepared college freshmen. *Primus, 5,* 229–252.

Olsen, J. (2019). The Nominal Group Technique (NGT) as a Tool for Facilitating Pan-Disability Focus Groups and as a New Method for Quantifying Changes in Qualitative Data. *International Journal of Qualitative Methods*. https://doi.org/10.1177/1609406919866049.

Osborne, J., and Dillon, J. (2008). *Science education in Europe: Critical reflections*. London: The Nuffield Foundation.

Packer, M.J., & Goicoechea, J. (2000). Sociocultural and constructivist theories of learning: Ontology, not just epistemology. *Educational Psychologist, 35*, 227–241.

Pat Shien, P., and Tsai, C.Y. (2015). Impact of a Scientist-Teacher Collaborative Model on Students, Teachers and Scientists. *International Journal of Science Education, 37* (13). 2147-2169.

Patel, S., DeManie, S., Heafield, J., Banchi, L., and Prokop, A. (2017). The droso4schools project: Long-term scientist-teacher collaborations to promote science communication and education in schools. *Seminars in Cell and Developmental Biology, 70*. 73–84.

Peker, D. & Dolan, E. (2012). Helping students make meaning of authentic investigations: findings from a student–teacher–scientist partnership. *Cultural Studies of Science Education, 7*(1): 223–244.

Pietarinen,T., Vauras, M., Laakkonen, E., Kinnunen. R., and Volet. S. (2019). High school students' perceptions of affect and collaboration during virtual science inquiry learning. *Journal of Computer Assisted Learning, 35*(3), 334-338. https://doi.org/10.1111/jcal.12334

Puntambekar, S. & Hubscher, R. (2005). Tools for Scaffolding Students in a Complex Learning Environment: What Have We Gained and What Have We Missed?. *Educational Psychologist, 40*(1), 1-12. Retrieved April 23, 2019 from https://www.learntechlib.org/p/73421/.

Puntambekar, Sadhana & Hubscher, R. (2010). Tools for Scaffolding Students in a Complex Learning Environment: What Have We Gained and What Have We Missed?. *Educational Psychologist, 40*. 1-12. 10.1207/s15326985ep4001_1.

Rahm, J. (2007). Youths' and scientists' authoring of and positioning within science and scientists'work. *Cultural Studies of Science Education, 1*(3), 517–544.

Rahm, J. (2016). Project-Based Museum-School Partnerships in Support of Meaningful Student Interest- and Equity-Driven Learning Across Settings. *Canadian Review of Art Education, 43*(1)*, 184-198.*

Reglin, G. L. (1990). The effects of individualized and cooperative computer assisted instruction on mathematics achievement and mathematics anxiety for prospective teachers. *Journal of Research on Computing in Education, 23*, 404–412.

Resnick, L.B. (1991). Shared cognition: Thinking as social practice. In L.B. Resnick, J.M. Levine, & S.D. Teasley (Eds.), *Perspectives on socially shared cognition*. 1–20. Washington, DC: American Psychological Association.

Riessman, C.K. (1993). *Narrative Analysis. Qualitative Research Methods Series*, No. 30. Newbury Park, CA: Sage.

Roggen, E.L. (2011). In vitro Toxicity Testing in the Twenty-First Century. *Frontiers in Pharmacology, 2,* 3. doi: 10.3389/fphar.2011.00003

Rogoff, B. (1986). Adult assistance of children learning. In T. E. Raphael (Eds.) *The Contexts of school-based literacy.* 27-40. New York: Random House.

Rolfe, G., Freshwater, D. and Jasper, M. (2001). *Critical reflection in nursing and the helping professions: a user's guide*. Basingstoke: Palgrave Macmillan.

Roschelle, J. (1992) Learning by collaborating: Convergent conceptual change. *Journal of the Learning Sciences, 2*, 235–276.

Royal Society. (2006). *Survey of factors affecting science communication by scientists and engineers*, The Royal Society. Retrieved April 21, 2020, from http://royalsociety.org/uploadedFiles/Royal_Society_Content/Influencing_Policy/Themes_and_Projects/Themes/Governance/Final_Report_-_on_website_ _and_amended_by_SK.pdf

Rubio, C.P., Hernandez-Ruiz, J., Martinez-Subiela. S., Travijonaviciute, A., and Ceron, J.J. (2016). Spectrophotometric assays for total antioxidant capacity (TAC) in dog serum: an update. *BMC Veterinary Research, 12,* 166. doi: 10.1186/s12917-016-0792-7

Rudolph, J.L. (2019). *How We Teach Science: What's Changed, and Why It Matters*. Harvard University Press, Cambridge, Massachusetts.

Sacks, H. (1992). *Lectures on conversation, Vol.1 (Autumn 1964–Spring 1968)*. Oxford: Blackwell.

Sadler, T.D., Burgin, S., McKinney, L., and Ponjuan, L. (2010). Learning science through research apprenticeships: A critical review of the literature. J*ournal of Research in Science Teaching, 47*, 235–256.

Salas, J., Segundo, J., Álvarez, C., Arellano, J., & Pérez, A. (2014). Evaluation of the Use of Two Teaching Techniques in Engineering. I*nternational Journal of Engineering Pedagogy,, 4*(3), 4. http://dx.doi.org/10.3991/ijep.v4i3.3287.

Salonen, A., Hartikainen-Ahia, A., Hense, J., Scheersoi, A., & Keinonen, T. (2017). Secondary school students' perceptions of working life skills in science-related careers. *International Journal of Science Education, 39*(10), 1339-1352.

Saner, H., McCaffrey, D., Stecher, B., Klein, S., & Bell, R. (1994). The effects of working in pairs in science performance assessments. *Educational Assessment, 2*(4), 325–338.

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-based Learning, 1*(1). Retrieved from http://dx.doi.org/10.7771/1541-5015.1002.

Schielke, K., Schmidt, K., & Judith, A.S. (2014). Scientists in the classroom. ISTA. *Spectrum, 40* (1). 19-23.

Schwichow, M., Zimmerman, C., Croker, S., & Härtig, H. (2016). What students learn from hands-on activities. *Journal of Research in Science Teaching, 53*(7), 980-1002.

Scruggs, T. E., Mastropieri, M. A., & Graetz, J. (2003, April). *Effects of classwide peer tutoring on learning in inclusive high school chemistry classes*. Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Serdyukov,P. (2017) "Innovation in education: what works, what doesn't, and what to do about it?", *Journal of Research in Innovative Teaching & Learning,10* (1), 4-33. https://doi.org/10.1108/JRIT-10-2016-0007.

Siribunnam, S., Nuangcharlem, P., & Jansawang, N. (2014). Socio-scientific Decision Making in the Science Classroom. *International Journal for Cross-Disciplinary Subjects in Education, 5* (4). 1777-1782.

Smith, M. E., Hinckley, C. C., and Volk, G. L. (1991). Cooperative learning in the undergraduate laboratory. *Journal of Chemical Education, 68,* 413–415.

Stamovlasis, D., Dimos, A., and Tsaparlis, G. (2006). A study of group interaction processes in learning lower secondary physics. *Journal of Research in Science Teaching*, *43*(6). 556-576.

Stanford University Center for Teaching and Learning. (2001). Problem-Based Learning. *Speaking of Teaching, 11*(1), 1-8. Retrieved from: http://web.stanford.edu/dept/CTL/Newsletter/

Strobel , J., Wang, J., Weber. N.R., & Dyehouse, M. (2013). The role of authenticity in design-based learning environments: The case of engineering education. *Computers & Education, 64.* 143–152

Strobel, J., & van Barneveld, A. (2009).When PBL is more effective? A metasynthesis of meta-analyses comparing PBL to convenyional classtooms. (Abstract). *The Interdisciplinary Journal of Problem-Based Learning, 3*(1).

Tanner, K. D., Chatman, L., & Allen. D. (2003). Approaches to Biology teaching and learning: Science teaching and learning across the school-university divide-cultivating conversations through scientist-teacher partnerships. *Cell Biology Education, 2*, 195-201.

Torri, K. (2018). *Connecting the worlds of learning and work: Prioritising school-industry partnerships in Australia's education system*. Mitchell Report No. 02/2018, Victoria University.

Trautmann, N.M., and MaKinster, J.G. (2005). *Teacher/Scientists Partnerships as Professional Development: Understanding How Collaboration Can Lead to Inquiry.* Paper presented at AETS International Conference, Colorado Springs.

Trisdiono, H., Siswandari, S., Suryani, N., and Joyoatmojo, S. (2019). Multidisciplinary Integrated Project-Based Learning to Improve Critical Thinking Skills and Collaboration. *International Journal of Teaching, Learning and Educational Research, 18* (1), https://doi.org/10.26803/ijlter.18.1.2.

Tse, W., & Chan, W. (2003). Application of Problem-Based Learning in an Engineering Course. *International Journal Of Engineering Education, 19*(5), 747-753. Retrieved from https://www.ijee.ie/articles/Vol19-5/IJEE1440.pdf

Tuckett, Anthony. (2005). Applying Thematic Analysis Theory to Practice: a researcher's experience. *Contemporary nurse, 19.* 75-87. 10.5172/conu.19.1-2.75.

Tudge, J. R. H. (1992). Processes and consequences of peer collaboration: A Vygotskian analysis. *Child Development*, *63*(6), 1364–1379.

Tudge, J., & Scrimsher, S. (2003). Lev Vygotsky on education: A cultural-historical, interpersonal, and individual approach to development. In B. Zimmerman & D. Schunk (Eds.), *Educational psychology: A century of contributions*. 207-228. Mahwah, NJ: Lawrence Erlbaum Associates

Turner, J. C. (1995). The influence of classroom contexts on young children's motivation for literacy. *Reading Research Quarterly, 30*(3), 410–441.

Ufnar, J. A., & Shepherd, V. L. (2018). The scientist in the classroom partnership program: An innovative teacher professional development model. *Professional Development in Education, 44*(3), 1-17.

Vaismoradi, M., Jones, J., Turunen, H., & Snelgrove, S. (2016). Theme development in qualitative content analysis and thematic analysis. *Journal of Nursing Education and Practice, 6*(5). 100-110.

Valiente, C., Swanson, J., & Eisenberg, N. (2012). Linking Students' emotions and academic achievement: When and why emotions matter. *Child development Perspectives, 6*,129−135.

van Boxtel, C., van der Linden, J., & Kanselaar, G. (2000). Collaborative learning tasks and the elaboration of conceptual knowledge. *Learning and Instruction, 10*(4), 311–330. https://doi.org/10.1016/S0959-4752(00)00002-5

Van Griethuijsen, R. A., Van Eijck, M. W., Haste, H., den Brok, P. J., Skinner, N. C., Mansour, N., & BouJaoude, S. (2015). Global patterns in students' views of science and interest in science. *Research in Science Education, 45*(4), 581-603.

Vygotsky, L. (1978). *Interaction between Learning and Development (pp. 79-91). In Mind in Society*. (Trans. M. Cole). Cambridge, MA: Harvard University Press.

Walker, A. & Leary, H. (2009). A problem-based learning meta-analysis: Differences across problem types, implementation types, disciplines and assessment levels. *Interdisciplinary Journal of Problem-based Learning, 3*(1), 12-43.

Webb, N. M. (1993). Collaborative group versus individual assessment in mathematics: Processes and outcomes. *Educational Assessment, 1*(2), 131–152.

Webb, N. M., Nemer, K. M., Chizhik, A. W., & Sugrue, B. (1998). Equity issues in collaborative group assessment: Group composition and performance. *American Educational Research Journal, 35*(4), 607–651.

Webb, N.M. (1984a). Peer interaction and learning in cooperative small groups. *Journal of Educational Psychology, 74*, 642–655.

Webb, N.M. (1984b). Sex differences in interaction and achievements in cooperative small groups. *Journal of Educational Psychology, 76*, 33–44.

Webb, N.M. (1989). Peer interaction and learning in small groups. *International Journal of Educational Research, 13*, 21–39.

Webb, N.M. (1991). Task related verbal interaction and mathematics learning in small groups. *Journal of Research in Mathematics Education, 22*, 366–389.

Weber, M. (1978). Max Weber: Selections in Translation (W. Runciman, Ed.; E. Matthews, Trans.). Cambridge: Cambridge University Press. doi:10.1017/CBO9780511810831

Wertsch, J. V. (1984). The zone of proximal development: Some conceptual issues. New Directions for Child Development, 23, 7-18. http://dx.doi.org/10.1002/cd.

Wilkinson, S. (1988). Focus groups in health research: Exploring the meanings of health and illness. *Journal of Health Psychology, 3*(3), 329-348.

Wood, D. J., Bruner, J. S., & Ross, G. (1976). The Role of Tutoring in Problem Solving. *Journal of Child Psychiatry and Psychology, 17*, 89-100.

Woods-Townsend, Kathryn & Christodoulou, Andri & Rietdijk, Willeke & Byrne, Jenny & Griffiths, Janice & Grace, Marcus. (2015). Meet the Scientist: The Value of Short Interactions Between Scientists and Students. *International Journal of Science Education, 6*. 10.1080/21548455.2015.1016134.

World Economic Forum (2018). *The future of jobs report.* Geneva, Switzerland: Author. p.4.

Wormstead, S.J., Becker, M.L., and Congalton, R.G. (2002). Tools for Successful Scientists-Teachers-Students Partnerships. *Journal of Science Education and Technology, 11 (3),* 277-287.

Yetter, G., Gutkin, T., Saunders, A., Galloway, A.M., Sobansky, R.R., & Song, S.Y. (2006). Unstructured Collaboration Versus Individual Practice for Complex Problem Solving: A Cautionary Tale, *The Journal of Experimental Education*, *74*(2), 137–159.

Zhou, S.N., Zeng, H., Xu, S.R., Chen, L.C., & Xiao, H. (2019). Exploring changes in primary students' attitudes towards science, technology, engineering and mathematics (STEM) across genders and grade levels. *Journal of Baltic Science Education, 18*(3), 466-480.