The Impacts of Different Flipped Classroom Pedagogies on Secondary Students' Self-Regulated Learning Abilities, Learning Achievement, and Science Process Skills

by

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Statement of Originality

I, LEE, Lit Hong, hereby declare that I am the sole author of the thesis and the material presented in this thesis is my original work except those indicated in the acknowledgement. I further declare that I have followed the University's policies and regulations on Academic Honesty, Copyright and Plagiarism in writing the thesis and no material in this thesis has been submitted for a degree in this or other universities.

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Abstract

The flipped classroom approach has gained prominence in education by reallocating the teaching of content knowledge into lecture-videos and creating more class time for student-centered learning activities. However, the efficacy of the flipped classroom regarding enhancing students' self-regulated learning abilities, learning achievement, and science process skills is questionable in secondary science education. This research, therefore, employs a mixed-methods and quasi-experimental design to investigate the effectiveness of a traditional flipped classroom pedagogy and a modified flipped classroom pedagogy that is integrated with a self-regulated learning strategy and technology-enhanced Predict-Observe-Explain activities using mobile loggers in a secondary school in Hong Kong. In this study, an experimental group of modified flipped classrooms (n = 63) and a control group of traditional flipped classrooms (n = 61) were employed among four Form 2 (Grade 8) science classes with different learning abilities (higher/lower) for seven months between 2018 and 2019. Quantitative data, including the pre- and post-scores of students' self-regulated learning abilities and basic and integrated science process skills, were measured using widely-recognized instruments. Data regarding the students' learning achievement were assessed using a self-developed performance test. In addition, the post-scores of the measurements were collected from a historical control group of non-flipped traditional classrooms (n = 63) from the previous academic year for further comparison. Following the quantitative analysis, 16 students were selected purposefully for sequential semi-structured interviews to elaborate the quantitative findings. The results indicate that the modified flipped classroom pedagogy was more effective at improving the students' time-management ability, but not efficacious in enhancing their other subscales of self-regulated learning abilities when compared with the traditional flipped classroom pedagogy because of the similarity of the goal orientation among the flipped approaches. The results also show that the modified flipped classroom pedagogy was more effective at improving several subscales of the students' science process skills when compared with the traditional flipped classroom pedagogy. Furthermore, the findings demonstrate that the modified flipped classroom pedagogy was more effective at enhancing several subscales of the students' self-regulated learning abilities and learning achievement in comparison with the non-flipped traditional classroom approach. These findings are attributed to the benefits of the self-regulated Predict-Observe-Explain strategy as well as the real-time streaming and data gathering features of the mobile laboratory using mobile loggers. The results also reveal that the modified flipped classroom approach enhanced the students' self-regulated learning abilities regardless of their learning abilities, but that such an approach was particularly advantageous for the higher achievers in improving their skill in stating hypotheses. Finally, the limitations and difficulties identified in this study are discussed and recommendations for future research and practice are suggested. The research findings have significant implications for the teaching and learning of science, as well as contributing empirical evidence through the successful design and implementation of the modified flipped classroom pedagogy in secondary science education.

Keywords: flipped classroom, technology-enhanced learning, self-regulated learning, science process skills, secondary science education

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List of Abbreviations

BSPS Basic Science Process Skills

CDC Curriculum Development Council

CLT Cognitive Load Theory

EDB Education Bureau

EdUHK The Education University of Hong Kong

FC Flipped Classroom

HL Higher Learning ability

ISPS Integrated Science Process Skills

IT Information Technology

LA Learning Achievement

LL Lower Learning ability

LMS Learning Management System

POE Predict-Observe-Explain

SCLT Student-Centered Learning Theories

SDT Self-Determination Theory

SL Scientific Literacy

SPS Science Process Skills

SRL Self-Regulated Learning

TEL Technology-Enhance Learning

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Chapter 1: Introduction

1.1 Introduction

This chapter initially describes the background of the research (Section 1.2). Then, the research gap concerning flipped classroom (FC) learning in secondary science education (Section 1.3) is discussed. The problem statement, research purpose, and research questions are proposed in accordance with the research gap (Section 1.4), and the research design is overviewed (Section 1.5). Finally, the significance of the study is assessed (Section 1.6), and the organization of this thesis is outlined (Section 1.7).

1.2 Background of the Research

This section highlights the problems of teaching and learning science in Hong Kong secondary schools (Section 1.2.1), the strategy of using information technology in education (Section 1.2.2), and the challenges involved in science education in Hong Kong (Section 1.2.3).

1.2.1 Problems of Teaching and Learning Science in Hong Kong Secondary Schools

Teaching and learning in Hong Kong have been criticized for many years as spoon-feeding students for the sole purpose of drilling them to achieve higher examination scores (Yuen, 2017). These scores decide their progression through the education system (Morris, Adamson, & Ebrary, 2010).

Different stakeholders in Hong Kong's education system, including the parents, teachers, school leaders, and even the Education Bureau (EDB), have often misinterpreted student scores in public examinations—including the heavily criticized Territory-Wide System Assessment at Primary 3 and the only high-stakes pre-university public exam, the Hong Kong Diploma of

Secondary Education Examination at Secondary 6—as the ultimate benchmark for educating the next generation (Kwok, 2017). Therefore, from teachers' perspectives, innovative, technology-supported, and student-centered pedagogies have been implemented to a limited degree in science lessons owing to the insufficient teaching time available under the tight syllabuses in secondary science education in Hong Kong (Cheng, So, & Cheung, 2000; Cheung, 2007; Yeung, Lee, & Lam, 2012; Yeung, Lee, Wong, & Wong, 2013).

In addition to the lack of class time, the need to teach large classes (Cheung, 2007; Yeung et al., 2012), often with increasing learning diversity (Yeung et al., 2012; Yeung et al., 2013), also prevents teachers from applying student-centered pedagogies, such as case-based, problem-based, and inquiry-based learning, in science lessons. Teacher concerns about the shortage of effective instructional materials and teaching resources from the local education bureau (Cheung, 2007; Yeung et al., 2012), as well as teacher inertia toward changing old practices (Yeung et al., 2012), have been raised as issues in the literature.

In addition to the role of teaching science in class, teachers have also reported that their time is fully occupied by a heavy workload of leading extra-curricular activities, completing administrative work, and participating in various types of studies, often preventing them from participating in research on student-centered pedagogies in the classroom (Chow, Chu, Tavares, & Lee, 2015). The duties of being a class teacher include daily classroom and class club duties, student counseling, and communication with parents, which are deemed to be time-consuming by many frontline teachers (Leung, Wong, & Pow, 2002). Consequently, chalk-and-talk lecturing, which is often regarded as a time-saving teacher-centered strategy of exposition, is still widely employed by many Hong Kong secondary school teachers (Yeung et al., 2012).

1.2.2 The Use of Information Technology in Hong Kong Education

To keep up with the exponential growth in the use of communication and information technology (IT), the first strategic plan and implementation of IT in Hong Kong education was officially launched in 1998. Significant improvements were then made to the hardware in schools, such as IT infrastructure and equipment for connecting to the internet, as well as teachers' basic training in embracing IT as a teaching tool for engaging students in the classroom (Education and Manpower Bureau, 2004). Throughout the early 2000s, increasing emphasis was placed on developing holistic and strategic school plans for using IT to meet the needs of schools' visions effectively. This approach was put into effect by enhancing school capacities for teaching and learning, as well as by prioritizing human factors, including school leaders, teachers, parents, students, and IT support staff, to pursue a desirable paradigm shift from a teacher-centered classroom to a student-centered electronic-learning (e-learning) environment. Such actions comprise the second and third strategies of applying IT in education in Hong Kong (Education and Manpower Bureau, 2004; EDB, 2007). According to the most up-to-date consultation document on the Fourth Strategy on Information Technology in Education released in 2014, "unleashing the learning power of all our students to learn and to excel" through interactive learning and teaching experiences has become the ultimate goal of using IT in education in Hong Kong in the 21st century (EDB, 2014, p. 1).

To achieve this goal, pedagogies that leverage mobile technology and internet resources to achieve the aim of "strengthening students' self-directed learning" have been suggested by the EDB (2014, p. 7). The consultant document exemplifies the use of flipped classroom (FC) by a local primary school teacher who used videos of presentations and assignments on the learning management system (LMS) as a substitute for classes during the closure of schools for weeks due to the outbreak of an epidemic disease (EDB, 2014). Bishop and Verlege (2013) provide a clear definition of FC "as an educational technique that consists of two parts: (a) interactive group learning activities inside the classroom, and (b) direct computer-based individual instruction outside the classroom" (p. 5).

In accordance with many studies, FC has gained much attention in various sectors of education in many countries over the past decade as it extends the amount of lesson time for the implementation of student-centered learning activities (Bergmann & Sams, 2014; Bergmann & Smith, 2017; Bishop & Verleger, 2013). In Hong Kong, a proliferation of seminars and professional training workshops on the implementation of FC in secondary schools has been provided by the EDB, and many workshops on the experience of using the FC approach have been conducted among frontline teachers organized by professional communities such as the FlipEducators@HongKong and Hong Kong Education City (Hong Kong Education City Limited, n.d.). In view of the delayed resumption of school for several months following the Lunar Holiday as a result of the new coronavirus outbreak in Hong Kong, the EDB has encouraged secondary school teachers to use e-learning platforms combined with the FC approach for teaching and learning at home. The EDB has promoted numerous online and self-learning resources, such as (i) Star, which is a web-based central assessment item bank for online assessment; (ii) Educational Television resources, which provide 15- to 20-minute television programs, short videos, animations, songs, and images that cover the Hong Kong primary and secondary school curricula in most subjects; and (iii) Small Campus, which is a game-based self-learning platform (EDB, 2020).

Nevertheless, there is no supporting evidence that solely providing these suggested online resources for students can lead to a successful FC; in-class, face-to-face, and student-centered teaching and learning must not be ignored. Furthermore, in-depth research on the effectiveness of implementing FC at secondary level in Hong Kong is very limited. Empirical research concerning how effectively FC can enhance student academic and affective achievements for specific subject domains, such as learning achievement (LA) and science process skills (SPS) emphasized in science education, is also lacking.

1.2.3 Challenges of Secondary Science Education in Hong Kong

According to the latest curriculum guide for science education (Primary 1 to Secondary 6) prepared by the Curriculum Development Council (CDC) (2017a), the enhancement of students' scientific literacy (SL)—"which refers to students' ability to apply scientific knowledge and science process skills to tackle issues and problems related to their daily life and the natural world" (p. 5)—is one of the main focuses in this newly updated Key Learning Area (KLA) for the science curriculum in schools with pupils aged 6 to 18 in Hong Kong (CDC, 2017a). To achieve this aim, it is suggested that the learning and teaching of science should develop students to become self-directed lifelong learners to build their deep-learning competencies and their ability to acquire, integrate, and apply knowledge and skills to solve authentic or real-life problems (CDC, 2017a, p.62).

In line with the aforementioned school KLA science curriculum, the secondary school science (Secondary 1–3) curriculum specifically emphasizes the development of students' SL and SPS (CDC, 2017b):

> The curriculum is designed for the development of scientific literacy, the associated science process skills, together with the awareness of the impact that science has on our lives and environment for students at junior secondary level. This helps students to deal with the opportunities and challenges in a wide variety of personal and social

contexts in such an era of rapid scientific and technological change for students at junior secondary level. (p. 2)

Nevertheless, scientific literacy among Hong Kong junior secondary students dropped in rank from second to ninth over the past two cycles (2012 and 2015) in one of the largest international assessment studies, the Programme for International Student Assessment (PISA). The PISA assesses students' SL in terms of three competencies and three types of knowledge in the personal, local, and global contexts (OECD, 2016), which might reflect students' SPS in certain extent. These competencies are (a) explaining phenomena scientifically, (b) evaluating and designing scientific enquiry, and (c) interpreting data and evidence scientifically. The competencies are interrelated with three types of knowledge: (i) content knowledge, which supports explaining phenomena scientifically, and (ii) procedural and (iii) epistemic knowledge, which help design scientific inquiry and interpret data (OECD, 2016; 2019a) (see Figure 1). Moreover, although Hong Kong students' SL rank remained ninth in the latest PISA (2018), the overall mean score dropped to 517 compared with 523 in PISA 2015 (OECD, 2019b; Schleicher, 2019; The Government of Hong Kong Special Administrative Region, 2019), suggesting that the SPS of secondary school students in Hong Kong has slightly regressed recently.

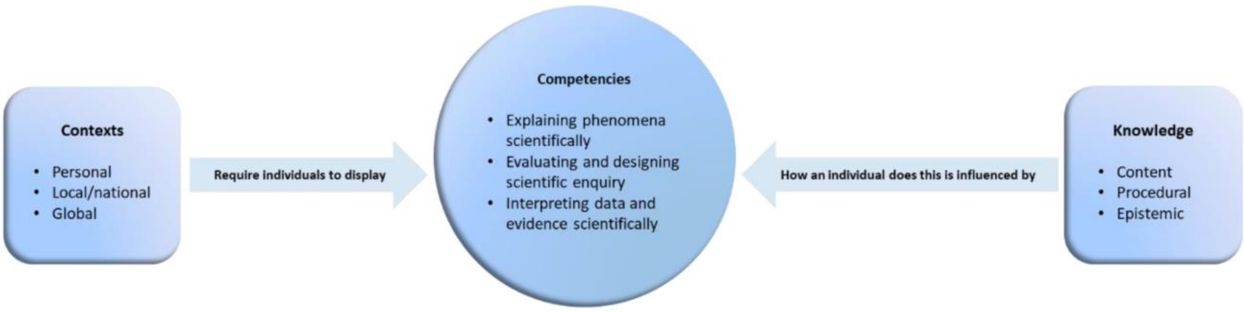

Figure 1. The framework of scientific literacy in the PISA

Reprinted from *PISA 2018 Assessment and Analytical Framework* (p. 103), by OECD, 2019a, Paris: OECD Publishing.

As well as the overall performance in the PISA, the performance of Hong Kong students is relatively strong in science content knowledge related to the competency of explaining phenomena scientifically. However, their performance is relatively weak in terms of scientific inquiry, including procedural and epistemic knowledge, as well as competencies in designing scientific inquiry and interpreting data (Lau & Lam, 2017). These findings suggest that more inquiry-based and student-centered pedagogies should be introduced into the Hong Kong secondary school science education program at a suitable time.

A transformation of the current teaching pedagogies should be considered to address the aforementioned constraints and challenges (EDB, 2015; Yeung et al., 2012; Yeung et al., 2013). Innovative teaching methods (e.g., Yeung, 2002), technology-enhanced learning (e.g., Tho & Yeung, 2014; Yeung, 2011), and scientific investigation (e.g., Tho & Yeung, 2015; 2016; 2018) are highly recommended to be employed in teaching and learning science subjects (Yeung et al., 2012). Hence, the feasibility of introducing innovative and technology-enhanced methods that incorporate the FC approach in promoting student science learning—and particularly students' SPS—is a worthwhile area of investigation.

1.3 Research Gap

This section discusses the research gap regarding how FC impacts student learning (Section 1.3.1), and the theoretical frameworks that underlie the design of FC (Section 1.3.2).

1.3.1 Impacts of the Use of Flipped Classroom in Student Learning

The flipped classroom approach has attracted significant attention from academics (Abeysekera & Dawson, 2015; Bishop & Verleger, 2013) because of its ability to extend lesson time to incorporate student-centered learning activities in the classroom by arranging lectures prior to the lesson (Bergmann & Sams, 2014; Bergmann & Smith, 2017). Experimentation on the use of FC can be found in many disciplines, from elementary school mathematics classes (Lai & Hwang, 2016) to university-level multimedia courses (Enfield, 2013). Extensive research has also been conducted on the impacts and challenges involved in the use of FC in higher education (Bishop & Verleger, 2013; Lo & Hew, 2017; O'Flaherty & Phillips, 2015; Talbert, 2017).

By considering various systematic reviews of flipped learning across different disciplines in higher education (Bernard, 2015; Betihavas, Bridgman, Kornhaber & Cross, 2016; Bishop & Verleger, 2013; Giannakos, Krogstie, & Chrisochoides, 2014; Lin & Hwang, 2019; O'Flaherty & Phillips, 2015), there are three common categories of positive effects on student learning in FC: (a) academic achievement (e.g., González-Gómez, Jeong, Rodríguez, & Cañada-Cañada, 2016); (b) engagement and motivation (e.g., Chen, Wang, Kinshuk, & Chen, 2014); and (c) satisfaction and attitude (e.g., Enfield, 2013). In a recent systematic literature review of 48 FC studies published between 2017 and 2018 (Zainuddin, Haruna, Li, Zhang, & Chu, 2019), effects of FC on student (a) social interaction (Olakanmi, 2017) and (b) self-efficacy (Lin & Hwang, 2019) were also found.

Although there are many findings regarding the positive impacts of the use of FC in different studies, most studies were conducted in higher education contexts (Lo & Hew, 2017). In addition, most systematic reviews were restricted to higher education (e.g., Bishop & Verleger, 2013; O'Flaherty & Phillips, 2015), and some were limited to subject disciplines only offered at university, such as health professions education (Hew & Lo, 2018), medical courses (Lin & Hwang, 2019), nursing education (Bernard, 2015; Betihavas et al., 2016), and computer science education (Giannakos et al., 2014). Only one systematic literature review has focused on FC in primary and secondary schools (Lo & Hew, 2017), in which most studies were restricted to mathematics, with only two research articles identified on science education (i.e., Kettle, 2003) and chemistry education (i.e., Schultz, Duffield, Rasmussen, & Wageman, 2014).

Moreover, several studies have revealed that FC had no significant effect on the improvement of student performance when compared with a control TC (e.g., DeSantis, Curen, Putsch, & Metzger; 2015; Jensen, Kummer, & Godoy, 2015; Kirvan, Rakes, & Zamora, 2015). Some studies have argued that different levels of achievers perform differently in FC learning (Nouri, 2016). Therefore, the suggested impacts of the use of FC remain uncertain in disciplines that have only been studied to a limited extent, such as science at the junior secondary level. The impact of promoting students' SPS—which is an important indicator in addition to learning performance when assessing student science learning, as mentioned in the previous section—has not been thoroughly investigated either. Therefore, future research about the impacts of flipped learning should focus on students' LA and SPS.

According to the review of recent flipped learning research, numerous limitations to the research methods threaten the significance of the reported results. First, some of the existing studies compared their proposed FC approach with a control group in which the delivery of knowledge was conducted through traditional teaching methods. Hence, there is a lack of evidence to draw valid conclusions about whether the impacts were produced by the FC design or by the student-centered learning activities introduced during the class time of the FC (Jong, 2017). Second, the problem of the absence of a pre-test to measure of the initial equivalence among experimental and control groups for valid comparison was encountered in many of the existing studies (Lo & Hew, 2017). Third, the duration of the interventions in most of the existing studies were very short, ranging from four weeks to four months (e.g., Clark, 2015; Olakanmi, 2017; Song & Kapur, 2017), which may have led to a novelty effect of technology increasing student performance in the short term (Lo & Hew, 2017).

Thus, this research should take critical and serious consideration of the gaps and limitations of previous research to design a more robust study using the triangulation of both quantitative and qualitative evidence on improving students' LA and SPS.

1.3.2 Frameworks that Underlie the Design of Flipped Classroom

1.3.2.1 Theoretical Frameworks

Abeysekera and Dawson (2015) explicitly suggested that the FC approach is under-theorized. Similarly, other studies (e.g., O'Flaherty & Phillips, 2015; Presti, 2016; Seery, 2015) have also stated that there is a lack of thorough consideration of robust theoretical frameworks in flipped learning designs.

Recently, an increasing number of empirical research papers have considered educational theories such as self-determination theory (SDT; e.g., Sergis, Sampson, & Pelliccione, 2018) and cognitive load theory (CLT; e.g., Bhagat, Chang, & Chang, 2016). In addition to the importance of considering SDT and CLT in flipped learning (Abeysekera & Dawson, 2015), Talbert (2017) suggested a third theoretical framework, self-regulated learning (SRL) theory, should be addressed to support flipped learning.

Flipped learning and SRL coincide with each other because students' independent and proactive participation is highly important in the out-of-class activities of FC (Talbert, 2017). These SRL strategies are not only restricted to classroom pedagogy, but are also effectively established in any technologically enhanced learning environment (Lai & Hwang, 2016; Tabuenca, Kalz, Drachsler, & Specht, 2015). As suggested by Barnard, Lan, To, Paton, and Lai (2009), SRL also plays a critical role in making online learning succeed. Nonetheless, recent studies that have considered SRL theory in their flipped learning designs are very limited (Talbert, 2017), and those that measure the acquisition of SRL ability though flipped learning in secondary-level science education are also absent at the time of writing.

With extensive empirical findings that student-centered learning strategies (e.g., inquiry-based learning) are possibly ideal approaches for the promotion of students' SRL in science (Schraw, Crippen, & Hartley, 2006), this flipped learning research is worthwhile for integrating an SRL theoretical framework and in-class inquiry-based learning into the design of FC and investigating how students can improve their SRL abilities in their science learning.

1.3.2.2 Pedagogical Frameworks

In practice, students' lack of motivation to watch pre-recorded videos or study course content outside of the classroom is regarded as the most significant challenge for flipped learning (Zainuddin et al., 2019). Various researchers have proposed and employed different pedagogical strategies/frameworks to address this problem. For example, Lo, Lie, and Hew (2018) employed Merrill's first principles of instruction (2002) to deal with real-world problems in four subjects: mathematics, physics, Chinese language, and information and communication technology in a secondary school. Hung (2015) used a WebQuest active-learning strategy (Dodge, 1995) on an English language course at a Taiwanese university.

Zainuddin (2018) also incorporated a gamification strategy into FC in an Indonesian secondary school to motivate students to watch and familiarize themselves with pre-lesson videos before school. Jensen et al. (2015) employed the 5-E instructional model (Bybee et al., 2006)—which has been widely adopted in school science education—in a flipped learning biology course at a US university. In their FC, the first three phases—*Engage*, *Explore*, and *Explain*—were arranged online as pre-class homework assignments, while two sequential phases—*Elaborate* and *Evaluate*—were arranged for the classroom.

There is no single formula for the success of flipping a class, and further investigations regarding FC in different disciplines are expected. As mentioned by Abeysekera and Dawson (2015), small-scale localized interventions that study the efficacy of flipped learning in particular disciplines, classrooms, and students are necessary in future investigations. Recently, Lo and Hwang (2018) supported this direction of future research by addressing the importance of "examining the effects of flipped learning in reaching different learning objectives" (p. 446) despite a proliferation of studies on FC conducted in recent years.

Hence, in this FC research, with the aim of improving students' SPS and LA, a modified 5E pedagogical framework (Lo, 2017) was adopted for implementation. Pre-class online learning was incorporated with the engaging strategies in the same way as the notion of gamification, namely via a technology-enhanced Predict-Observe-Explain (POE) strategy that involves (a) POE (White & Gunstone, 1992), which is an active-learning strategy that can increase motivation (Schraw et al., 2006) and clarify scientific misconceptions (Bahar, 2003; Cinici & Demir, 2013); and (b) a mobile laboratory that uses innovative mobile loggers for remote scientific investigations (Yeung, Cheang, & Fok, 2015; Yeung et al., 2019). The in-class learning was conducted with a brief review of the out-of-class learning, a mini lecture (Lo, Lie, & Hew, 2018), and a scientific inquiry following the modified 5E pedagogical framework.

1.4 Problem Statement, Research Purpose, and Research Questions

This section describes the problem statement (Section 1.4.1), research purpose (Section 1.4.2), and research questions (Section 1.4.3) of this study.

1.4.1 Problem Statement

As mentioned previously, the background of the current educational challenge urges a paradigm shift toward student-centered learning to improve secondary school students' SRL abilities, LA, and SPS in Hong Kong. Via a consideration of the current research gaps and the feasibility of grounding suitable theories in design and implementation, a modified FC using a technology-enhanced POE strategy with the utilization of an innovative mobile data logger (FPOE) was proposed. However, it was not known whether and to what extent this modified FC approach, as well as a traditional flipped classroom approach (TFC), could improve students' SRL abilities, LA, and SPS. It was also not known how students with different learning abilities would perceive and engage in the activities provided in both the pre-class and in-class learning of the FPOE that is specialized for secondary school science education in Hong Kong.

1.4.2 Research Purpose

The purpose of this research is to examine and compare the effectiveness of a modified FC approach using a self-regulated POE strategy and innovative mobile loggers (FPOE) with a TFC approach in terms of the improvements of SRL abilities, LA, and SPS among S.2 (Grade 8) science students in a government-aided secondary school in Hong Kong. Furthermore, the efficacies of the FC approaches (FPOE and TFC) are compared with a historical non-flipped traditional classroom (TC), and the effects of the FC approaches (FPOE and TFC) on students with different learning abilities (lower and higher) are also studied.

1.4.3 Research Questions

Four research questions (RQs) were proposed to address the purpose of this study:

RQ1: Can the FPOE improve students' SRL abilities, LA, and SPS in comparison with the TFC?

RQ2: Are there differences in the improvements of students' SRL abilities, LA, and SPS among different pedagogical approaches (FPOE vs. TFC vs. TC)? If yes, which is the most effective?

RQ3: Do student learning abilities (lower and higher) affect the improvements of their SRL abilities, LA, and SPS in different flipped pedagogical approaches (FPOE and TFC)?

RQ4: How and to what extent do the FPOE and TFC help students with different learning abilities to improve their SRL abilities, LA, and SPS?

1.5 Nature of Study

This mixed-methods research employed a non-equivalent control group pre-test–post-test design of a quasi-experiment (Campbell, Stanley, & Gage, 1963) that comprised an experimental group of modified FPOE (n =63) and a control group of TFC (n =61) for seven months in the S.2 (Grade 8) science subject between 2018 and 2019. Quantitative data of the pre-test and post-test scores in SRL, LA, and SPS were collected and analyzed, followed by the collection and analysis of qualitative interviews using the sequential explanatory strategy (Creswell & Plano Clark, 2007). Furthermore, post-test scores from an additional group of students from a TC (n =63)—comprising students with similar backgrounds from the previous academic year—were also collected for further quantitative analysis. In addition to the group of different pedagogies (the first independent variable), students with different learning abilities were also assigned to two different but intact classes (the second independent variable) for the investigation. Table 1 explains the arrangement of the intervention groups in this research.

Table 1
Arrangement of intervention groups in this research

Group	Pedagogy	Class	Learning ability	*N*	Year
Experimental (*n* =63)	Modified flipped classroom (FPOE)	2A 2C	Higher Lower	32 31	2018–2019
Control (*n* =61)	Traditional flipped classroom (TFC)	2B 2D	Higher Lower	31 30	2018–2019
Additional (*n* =63)	Non-flipped traditional classroom (TC)	2B 2C	Higher Lower	32 31	2017–2018

1.6 Significance of the Study

First, this research, which compares students' SRL abilities, LA, and SPS, provides a deep understanding of the effectiveness of both the subject-specific modified and traditional FC approaches in secondary school science education. The positive effects of these approaches on students with different learning abilities contribute to our knowledge regarding catering for students with differentiated learning in a science classroom. There are very few studies that have compared students' SRL abilities, LA, and SPS in the context of secondary school science education, and investigations on the effect of flipped learning on students with different learning abilities in science education are also lacking. Thus, this research is timely in addressing these issues.

Second, this research provides an insight into the importance of integrating FCs with student-centered learning activities, including pre-class POE and technology-enhanced mobile laboratory learning experiences, and in-class scientific inquiries that, consequently, meet the subject needs. Moreover, this research provides evidence for the design of FCs within the consideration of robust theoretical and pedagogical frameworks, including the SCLT, SDT, CLT, SRL theory and the 5-E instructional model. These frameworks meet curriculum objectives by improving student learning in secondary school science education. Consequently, this research fills the existing research gap regarding the lack of advancement of theoretical agendas or pedagogical frameworks in founding the FC (Abeysekera & Dawson, 2015; Lo & Hew, 2017; O' Flaherty & Philips, 2015; Presti, 2016).

Third, this research acts as a link between theory and practice in terms of supporting the feasibility of FC in secondary school practices in Hong Kong (EDB, 2014). By considering several recommendations suggested by other researchers regarding integrating the FC in practice, the strength of the modified FC approach, FPOE, can be further improved in practice. Difficulties encountered during the research might also provide important reference points for the generation of usable knowledge and solutions to be applied to the future implementation of the FC in secondary schools in Hong Kong. Thus, this research fills the design and practice gap regarding implementing FC in secondary schools (Lo, 2018).

Finally, the successful experience of incorporating the FPOE also demonstrates the possibility of flipping other science-related subjects at different levels, such as senior-level physics, chemistry, and biology in secondary education. Science, technology, engineering and mathematics (STEM) education might also be promoted with the help of the FC approach, as "STEM subjects contain an abundance of principles and abstract concepts which students need to *know* before being able to move on to more practical, authentic applications" (Huber & Werner, 2016, p. 267).

1.7 Organization of the Thesis

This thesis is presented in five chapters. First, this introductory chapter includes the overview of this research, including the background of the study and the research gap, the problem statement, the research purpose, the RQs, and the nature and significance of the study. Chapter 2 (Literature Review) extensively reviews the literature that relates to the definition, frameworks, and empirical findings of the FC approach in education. Furthermore, a scoping review of flipped learning research that focuses on the FC designs, student impacts, and challenges in K-12 science subjects is presented. Moreover, studies necessary for the design of the FCs in this study are reviewed collectively. These studies include research on the POE strategy and technology-enhanced learning in science education, as well as studies about LA, SPS, and SRL abilities in primary and secondary science education. Chapter 3 (Methodology) describes the research contents, including the background of the participants and the rationale for targeting the population, as well as the designs of the intervention groups. In addition, the chapter describes the rationales for employing a quasi-experimental design with a mixed-methods approach, as well as explaining the choice of instruments and the validity and reliability of this study. Finally, the chapter outlines the procedures for quantitative and qualitative data collection, the methods for analysis, and the ethical considerations and limitations. Chapter 4 (Results) reports the qualitative and quantitative results that address the RQs. Chapter 5 (Discussion) discusses the research results in terms of students' SRL abilities, LA, and SPS under different pedagogical approaches and compares the findings with the key existing research evidence. Limitations and difficulties regarding implementing the flipped learning approaches, particularly the newly developed FPOE, are described and discussed. There are also recommendations for future research and practice. Finally, Chapter 6 (Conclusion) summarizes this study and draws a concluding statement about the research findings. The researcher's personal experience of the study is mentioned, and several important educational implications are suggested as closing remarks.

Chapter 2: Literature Review

2.1 Introduction

This chapter initially provides an extensive review of literature related to the FC approach, including its definitions (Section 2.2), and the theoretical and pedagogical frameworks for FC (Sections 2.3 to 2.5). Implications based on the review of the frameworks for this study are discussed. Moreover, because of a lack of reviews on current FC research focusing on science education at primary and secondary schools, a systematic review of FC research about current practices, impacts, and challenges in K-12 science was conducted to identify the research gap in this discipline (Section 2.6). In addition, literature studies on the learning activities of the modified FC (Section 2.7) in this study, including out-of-class technology-enhanced learning (TEL) in science education (Section 2.7.1), SRL strategies of out-of-class POE (Section 2.7.2.1) and in-class scientific inquiry (Section 2.7.2.2) are reviewed. The rationale for the assessments on LA, SPS, and SRL abilities in secondary science education (Section 2.8) are also discussed to narrow the scope for guiding the design of the FPOE for secondary school science education in this study. Finally, this chapter concludes by revealing a conceptual framework based on the research gaps and implications (Section 2.9).

2.2 Definitions of Flipped Classroom

In many recent studies, the terms *flipped classroom*, *flipped learning*, and *flipped classroom learning* have been used interchangeably, expressing the same notion that students attend pre-recorded lectures at home and are involved in learning activities at school (Bergmann & Sams, 2012). Other terms, including *inverted classroom*, *blended learning*, and *reversed learning*, have also been adopted to refer to the concept of flipped instructions (Bergmann & Sams, 2012; Chen et al., 2014; Lage, Platt, & Treglia, 2000). For instance, the simplest definition of the flipped (or inverted) classroom is provided by Lage et al. (2000): “Inverting the classroom means that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa" (p. 32).

However, this definition oversimplifies FC into a pedagogy regarding re-ordering classroom and at-home activities. The quote does not adequately describe what the instructional approach of the FC is (Lo & Hew, 2017). To have a clear picture of what the FC consists of, Bishop and Verleger (2013) articulated a definition of FC as a technology-supported teaching technique that rigorously requires (a) the use of instructional videos to teach knowledge content in out-of-class time; and (b) interactive student-centered learning activities in face-to-face lessons. Abeysekera and Dawson (2015) suggested a similar definition, with the addition that the FC requires "students to complete pre- and/or post-class activities to fully benefit from in-class work" (p. 3).

Existing research has suggested many examples of such activities, such as taking online quizzes (Chao, Chen, & Chuang, 2015; Wang, 2016); e-book quizzes (Lai & Hwang, 2016); completing content notes (Clark, 2015); taking notes (Kettle, 2013; Wang, 2016); participating in online group discussions, such as Google Doc (Kong, 2014); reading textbooks (Grypp & Luebeck, 2015) and articles (Clark, 2015); and exploring web-page links (Jong, 2017).

By referring to the previous definition, we should distinguish the FC approach from some traditional class preparation strategies, such as asking students to read textbooks before class (Lo & Hew, 2017), as self-study from a book (being an out-of-class study phase) does not involve the explanation of new concepts by teachers.

The Flipped Learning Network (2014) suggested another in-depth definition of FC with the term flipped learning:

> Flipped Learning is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter. (p. 1)

The Flipped Learning Network (2014) distinguishes the FC, which is a pedagogical re-organizing of direct instruction out of school, from flipped learning, which is a practice emphasizing student-centeredness and interactive engagement. To illustrate further the features of flipped learning, the Flipped Learning Network (2014) suggested a four FLIP pillars feature of FC that includes the following: (a) F-pillar, which refers to a flexible environment allowing for a variety of learning methods; (b) L-pillar, which refers to a learning culture focusing on student-centered pedagogies; (c) I-pillar, which refers to intentional content for maximizing class time purposefully; and (d) P-pillar, which involves a professional educator who utilizes and reflects on his/her own teaching practices (Flipped learning Network, 2014). However, detailed descriptions of the pedagogy dimension in both online and in-class learning environment are lacking in the four FLIP pillars.

To place greater emphasis on the pedagogical design of online and face-to-face learning, Chen, Wang, Kinshuk, and Chen (2014) proposed a modified definition of FC, FLIPPED, which was based on the four FLIP pillars with the addition of an extra (a) P-pillar, which refers to progressive networking activities about the FC; (b) E-pillar, which refers to engaging and effective learning experiences; and (c) D-pillar, which refers to a diversified and seamless learning platform (Chen et al., 2014).

Furthermore, Talbert (2017) echoed that, "flipped learning is more than just a kind of teaching technique – it is an entire philosophy that encompasses course design, specific teaching practices, and professional engagement" (p. 18). The FC also often represents an expansion of the curriculum rather than a simple re-arrangement of activities (Bishop & Verleger, 2013).

In accordance with the above-mentioned diversity of FC definitions, it should be emphasized that, "flipping the content in a class can, but does not necessarily, initiate flipped learning" (Flipped learning Network, 2014, p. 1). Courses by tutorial schools in Hong Kong, providing pre-recorded video lectures on delivering examination techniques promptly without any student-centered activities, should be excluded from the FC. Similarly, educators only providing students with TV broadcast programs, such as the Education TV offered by EDB, Knowledge for All and Knowledge Horizons offered by The Open University of Hong Kong, YouTube videos, or Khan Academy Videos or other types of online learning without further purposeful follow-up activities inside class time, should not be regarded as flipped learning.

The FC, as defined by the Flipped Learning Network (2014) and Talbert (2017), employs *individual space* to replace *class time*, and *group space* to replace *outside-class time*, making the definition of the FC more widely applicable to different educational settings, such as online undergraduate courses in which face-to-face teaching is absent. However, this research adopts the assumption that the FC should involve elements of both out-of-class instructional video-watching and in-class face-to-face learning activities (Bishop & Verleger, 2013), which is more applicable for the secondary school context. Lo and Hew (2017) also suggested that the FC should only require basic IT resources, such as a video-maker and internet access in K-12 education.

Finally, the design and implementation of the FC should not be restricted to a short period, nor be integrated into one or two segments of the curriculum. Instead, a robust FC design supported by pedagogical and other theories should be holistically incorporated throughout the student learning journey to orient their achievement competences (Abeysekera & Dawson, 2015; Bishop & Verleger, 2013; Kim, Kim, Khera, & Getman, 2014; Lo, 2017).

2.3 Overview of Theoretical and Pedagogical Frameworks of the Flipped Classroom

Flipped learning studies have been criticized as still being under-theorized (Abeysekera & Dawson, 2015; Lo, et al., 2018), and some have even claimed that the effects of FCs could be unanticipated if they are not grounded in a theoretical framework (e.g., Kim et al., 2014). Therefore, a proper grounding of pedagogical and other theories that benefit student learning should be vital in the design and implementation of the FC (Lo, 2018). The following sections illustrate and discuss the theoretical and pedagogical frameworks hypothesized or adopted in FC studies, with empirical findings from different educational contexts. Implications regarding the employment of suitable frameworks for this study are also discussed.

2.4 Theoretical Frameworks

Bishop and Verleger (2013) discussed how the FC approach was initially rooted in student-centered learning theories originating from Piaget's socio-cognitive conflict (Tudge & Winterhoff, 1993) and Vygotsky's (1978) zone of proximal development (ZPD). Abeysekera and Dawson (2015) later proposed two theoretical frameworks for the FC by using two major psychological theories: SDT and CLT. Talbert (2017) discussed the feasibility of another theory, SRL, to support the FC. Finally, Lo (2018) proposed an extension of Bishop and Verleger's (2013) and Abeysekera and Dawson's (2015) grounding of the FC based on the interdisciplinary perspectives of educational technology (Spector, 2016).

2.4.1 Student-Centered Learning Theories

According to Bishop and Verleger (2013), student-centered learning theories (SCLT) originated from Piaget's theory of cognitive conflict (CC) and Vygotsky's zone of proximal development (ZPD), which shape in-class activities, are the most important and critical components to flip a classroom. The FC cannot exist without applying such theories as a philosophical basis, even if there is a comprehensive array of technology-assisted video lectures provided outside the classroom (Bishop & Verleger, 2013).

Student-centered learning, as originating from Piaget's and Vygotsky's theories, founded the basis of active learning (Prince, 2004). This involves pedagogies of peer-assisted, collaborative, cooperative, and problem-based learning to engage students during FC class time (Bishop & Verleger, 2013). Lo (2018), in his research on grounding the FC on the foundations of educational technology, also supported Vygotsky's ZPD perspective. According to Vygotsky (1978), "ZPD is the distance between the actual developmental 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. (p. 86)"

Hence, providing students with challenging tasks (based on the evidence of pre-class data) and peer-assisted learning opportunities are two of the most important learning implications for the design of FC in-class activities (Lo, 2018). Furthermore, Lo and Hew (2017) suggested that different levels of problem-solving tasks should be designed for both underperforming and higher-ability students regarding their needs during the in-class learning period of their flipped mathematics classroom.

There are numerous studies that ground their FCs in SCLT for in-class activities in primary and secondary education. For example, Faulkner and Green (2015) employed a peer-instruction approach in a Grade 9–10 mathematics course in a United States (US) high school. The peer-instruction approach consisted of student-centered in-class activities that involved students firstly attempting conceptual questions without discussing and sharing the answers with the teachers, followed by committing their answers again with the agreement among peers (Faulkner & Green, 2015). During the process, the teacher asked challenging questions with the help of a mobile application, Socrative, which collected the students' responses and offered them feedback simultaneously. Teacher-student relationships and academic achievements in algebra and calculus were found to have improved (Faulkner & Green, 2015).

It is also not unusual for some FC studies to incorporate SCLT in online activities with the help of technology. For example, Hwang and Lai (2017) introduced interactive and constructivist activities in the pre-class learning of a mathematics course with the use of an e-book for Grade 4 students in a Taiwan elementary school. The results indicated that the e-book-based FC promoted students' efficacy and academic achievement in mathematics learning. The research finding also suggested that the interactive e-book learning environment, which consists of cloud services to allow students to access the learning content, make annotations, and raise questions seamlessly and continuously in different contexts, successfully served as the support for bridging out-of-class and in-class learning (Hwang & Lai, 2017).

2.4.2 Self-Determination Theory

Abeysekera and Dawson (2015) claimed that, according to self-determination theory (Deci & Ryan, 1985), the FC approach draws on student motivation. According to Ryan and Deci (2000), intrinsic motivation refers to "the inherent tendency to seek out novelty and challenges, to extend and exercise one's capacities, to explore, and to learn" (p. 70). Extrinsic motivation, in contrast, is described as "the performance of an activity in order to attain some separable outcome" (Ryan & Deci, 2000, p. 71). To increase students' intrinsic motivation and to maintain certain levels of extrinsic motivation in learning, three basic needs should be met: (a) competence, which refers to the mastering of the knowledge, skills, and behaviors required to be successful in a social context; (b) autonomy, which refers to the need for a sense of control and independence; and (c) relatedness, which refers to a sense of belonging within a social group (Ryan & Deci, 2000).

As suggested by Abeysekera and Dawson (2015), FC learning environments are likely to satisfy the three needs of students. For instance, the utilization of in-class time encourages students to be more actively engaged in the learning process, focusing on providing opportunities for them to be in charge of creating and disseminating knowledge. This involvement means students are more likely to meet their needs for autonomy and competence, which are often eliminated in the passive and transmissive TC. Furthermore, more active engagement in the interactive activities of small learning groups in FCs satisfies the need to relate with other classmates and teachers (i.e., relatedness; Abeysekera & Dawson, 2015).

Talbert (2017) pointed out the importance of student motivation in the FC as it is necessary for the FC learning processes, including completing the preparatory work outside class and engaging in the active-learning environment during lessons. However, there is a possibility that some students can be extrinsically motivated through the introduction of reward or punishment rather than the integrated regulation of the positive values associated with an FC course as recommended by Abeysekera and Dawson (2015).

There are several studies that have specifically grounded the FC with SDT in primary and secondary education. For example, Muir and Geiger (2016) conducted an exploratory case study in a Grade 10 mathematics extended class of an iPad school in Australasia. The researchers found that teacher and students were positive about their experiences in the FC. In particular, students reported that their needs of competence had been met because the online resources and tutorials helped their understanding and making use of mathematical techniques. The study also found that the accessibility and convenience of watching the self-authorized videos produced by the teacher provided students with a sense of autonomy, as well as relatedness between the students and their teacher (Muir & Geiger, 2016).

Sergis et al. (2018) utilized the SDT for their FCs implemented across three subjects in a high school: mathematics, ICT, and humanities. The empirical research findings revealed that the FC could fulfill the students' need for competence by creating a supportive environment with an improved exploitation of class time for engaging in collaborative activities, and by providing feedback and support from the teacher. Consequently, these elements build confidence in student engagement in the FC. The findings also claimed that the FC effectively supported the students' need for autonomy by engaging them in tasks in an autonomous manner so they could invest more time in student-centered activities instead of exposition via lecturing. Finally, the results suggested that the FC freed up lesson time for collaborative activities with scaffolding from both the teacher and classmates, leading to an internal sense of being part of a social context that answered the students' need for relatedness (Sergis et al., 2018).

On the other hand, Zainuddin (2018) conducted a pilot study comparing the differences in perceived competence, autonomy, and relatedness among 56 students aged 15 and 16 (Grades

10 and 11) between a gamified and non-gamified science classes in an Indonesia secondary school. The findings from that study indicated that his FC, which integrated pre-class gamification, supported the students' learning needs regarding SDT. In particular, students in the gamified FC perceived they had more opportunities to take ownership of their learning (competence), to do their work in their own time and place enjoyably and pleasurably (autonomy), and to compete with their classmates in the gamified quiz activities (relatedness).

2.4.3 Cognitive Load Theory

Cognitive load theory suggests human working memory has a limited capacity; thus, human working memory can only hold between five and nine chunks of information at a given time (Miller, 1956). The consideration of CLT creates implications when designing FC pedagogies, such as the belief that students should be encouraged not just to memorize facts and knowledge but to develop a connected understanding of the concepts they are learning (Talbert, 2017). As hypothesized by Abeysekera and Dawson (2015), the FC is such a pedagogical approach, providing students with pre-recorded videos so they can pause and replay in their individual space. This self-pacing function helps students to reduce their cognitive learning loads in both their individual space and group space active-learning (Abeysekera & Dawson, 2015; Talbert, 2017).

Bhagat et al. (2016) grounded their FC within a specified CLT of multimedia learning (CTML) (Mayer, 2001). This approach emphasized that students could learn better from (a) words and pictures than words alone, and (b) from narration than on-screen text in a high school mathematics class regarding teaching and learning trigonometry. The research findings suggested that both the LA and motivation of the students, especially low achievers, in the FC performed better than those in a control conventional class (Bhagat et al., 2016).

Furthermore, Slemmons et al. (2018), in their study of two FCs that incorporated either a long video or a short video in a middle school science classroom in the US, found that shorter videos (average five to seven minutes) helped students to engage and focus more on the video-watching and to retain and recall information and demonstrate understanding over a longer time according to students' self-reports.

Taking SDT and CLT together, Abeysekera and Dawson (2015) proposed a theoretical model focusing on SDT and CLT for empirical investigation in higher education (see Figure 2.1).

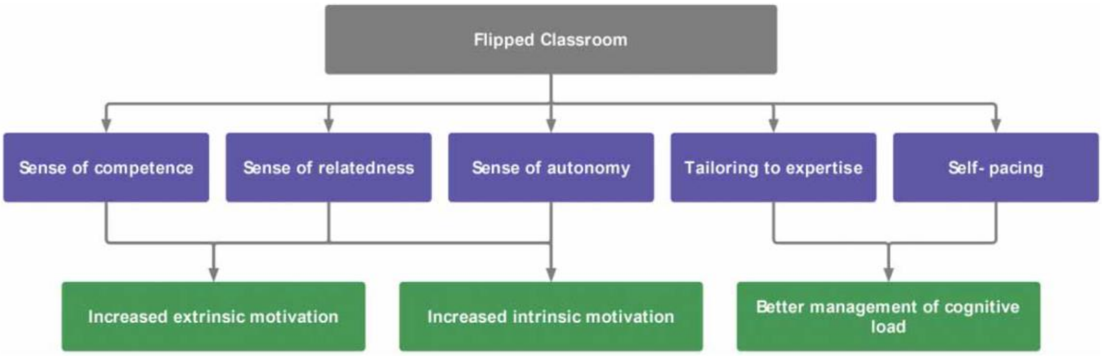

Figure 2.1. Theoretical model focusing on SDT and CLT for the FC

Reprinted from "Motivation and cognitive load in the flipped classroom: Definition, rationale and a call for research," by L. Abeysekera and P. Dawson, 2015, *Higher Education Research and Development, 34*(1), p. 10.

2.4.4 Self-Regulated Learning Theory

Talbert (2017) hypothesized that self-regulated learning theory and flipped learning go together because of the privileged position of independent learning activities in flipped learning. As suggested by Zimmerman (2002), SRL refers to students' self-generated thoughts, feeling, and actions, which are systematically oriented toward attainment of their goals. SRL also demands of students the development of skills and strategies that can include, but are not limited to, goal-setting, environmental structuring, self-monitoring, help-seeking, and task strategies (Zimmerman & Schunk, 2001).

Self-regulated learning contends that learning is regulated by a variety of interacting components, including (a) the cognitive component, which refers to the skills to translate, memorize, and recall information; (b) the metacognitive component, which refers to the skills to understand and monitor cognitive processes; and (c) the motivational component, which refers to the attitudes influencing the use and development of cognitive and metacognitive skills. To be self-regulated, all three components are required collectively (Zimmerman, 2000).

According to Pintrich (2000), self-regulatory processes consist of four phases: (a) forethought, planning, and activation, (b) monitoring, (c) control, and (d) reaction and reflection. Zimmerman (2002) suggested a similar description of self-regulatory processes in which students learn as self-regulated learners. The self-regulatory processes consist of three cyclical phases: (a) the forethought phase, in which the student analyzes the task with goal-setting and strategic-planning stemming from self-motivation beliefs; (b) the performance phase, in which the student employs specific planned strategies and behaviors suitable for striving for the learning goals; and (c) the self-reflection phase, in which the student evaluates their learning performance related to the goal-planning after each learning effort (Zimmerman, 2002). Figure 2.2 illustrates the three phases and subprocesses of the self-regulatory processes.

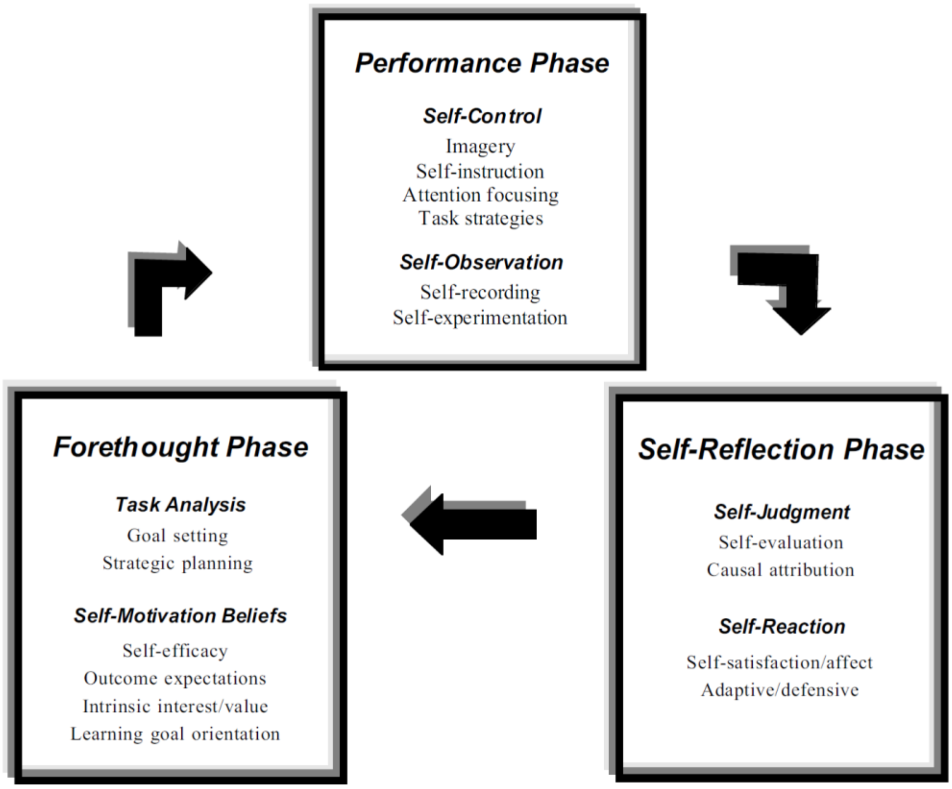

Figure 2.2. Phases and subprocesses of self-regulation

Reprinted from B.J. Zimmerman and M. Campillo (2003), "Motivating Self-Regulated Problem Solvers." In J.E. Davidson and R. Sternberg (Eds.), *The Psychology of Problem Solving* (p. 239). New York: Cambridge University Press.

Moreover, Barnard et al. (2009), based on Zimmerman and Schunk's theoretical view on SRL (2001), suggested six phases of self-regulation in the online environment: (a) goal-setting, (b) environmental structuring, (c) help-seeking, (d) task strategies, (e) time management, and (f) self-evaluation.

Reyna (2017) proposed a wave model that evaluates different aspects of Barnard et al.'s (2009) SRL in three stages of the FC context: (a) goal-setting, environmental structuring, and time management in pre-class learning; (b) task strategies and help-seeking during in-class activities; and (c) self-evaluation and self-consequence after the lessons. At the same time, motivational aspects including self-efficacy, goal orientations, task value, and attributions for failure and anxiety are also involved (see Figure 2.3). However, further empirical research on testing the validity and reliability of this wave model is needed.

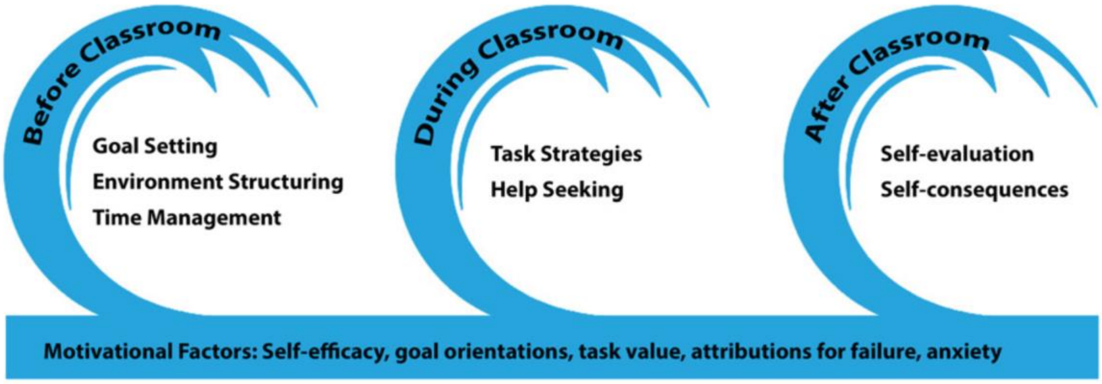

Figure 2.3. The wave model of SRL in FC

Reprinted from "Surfing the waves of self-regulated learning to evaluate flipped classrooms," By J. Reyna, 2017, *Proceedings of INTED2017 Conference 6th-8th March 2017, Valencia, Spain*, p. 8964.

Talbert (2017) echoed that an FC should involve self-regulated processes because the student is the one who takes responsibility for their learning in this context, not the teacher, who is usually the transmitter of knowledge in a TC (Talbert, 2017). The literature also suggested that, in the FC, students should be autonomous, self-directing and self-pacing (Muir & Geiger, 2016), especially in the online environment prior to face-to-face lessons (Reyna, 2017).

To assess the hypothesis on framing the FC with SRL theory, Lai and Hwang (2016) designed an FC incorporating a self-regulated monitoring system in which mathematics students were asked to establish learning goals based on their experiences on mathematics courses and were guided to perform self-evaluation on both the out-of-class e-book learning experience and in-class learning activities in a Taiwan elementary school. The findings suggested that the Grade 4 students who participated in the self-regulated FC had better strategies for planning and using their time for study, as well as higher self-efficacy and better academic performance compared with a conventional FC (Lai & Hwang, 2016). Lai and Hwang's (2016) research on using the SRL system in their FC in an elementary school echoes other research findings that the processes of self-regulation are teachable (Zimmerman, 2002), although few teachers effectively prepare students to learn on their own (Zimmerman, Bonner, & Kovach, 1996). On the other hand, Talbert (2017) suggested that the flipped learning environment could effectively support the development of students' SRL skills and behaviors by intentionally focusing on SRL when designing FC learning experiences, despite there being evidence that SRL happens simultaneously in the flipped learning environment (Talbert, 2017).

Some researchers have studied students' SRL in the FC, but most studies have been limited to higher education. For instance, Sletten (2017) measured students' SRL strategy by using the Motivated Strategies for Learning Questionnaire (MSLQ; Wolters et al., 2005) in his introductory biology course for a public research institution in the US. Sletten (2017) found that the students' perceptions, including preference and value of video, and viewing frequency significantly predicted their use of several SRL strategies. Moreover, Çakıroğlu and Öztürk (2017) found that, from their single-group experiment, students' SRL abilities of environmental structuring and goal-setting were developed to a high level in the pre-class session of the FC, whereas the SRL abilities of goal-setting, task strategies, and help-seeking of the students were also high in the problem-based activities in an information and communication technology course at a Turkey university. Sun, Xie, and Anderman (2018) examined the relationships between academic performance and the SRL constructs of (a) prior domain knowledge, (b) self-efficacy, and (c) the use of learning strategies in the FCs of university mathematics courses and found that self-efficacy and help-seeking strategies were positively related with student academic performance in both pre-lesson and in-class activities.

2.4.5 Spector's Six Pillars

Lo (2018) proposed an extension of the grounding of the FC (Abeysekera & Dawson, 2015; Bishop & Verleger, 2013) based on Spector's (2016) six pillars, which focus on the interdisciplinary perspectives of educational technology. The six pillars are as follows:

1. Communication: the way information is represented, transmitted, received, and processed.
2. Interaction: the human–human and human–computer interactions in supporting learning.
3. Environment: the context in which learning and instruction take place.
4. Culture: the varied sets of norms and practices of different communities.
5. Instruction: the process of facilitating learning and performance.
6. Learning: the stable and persisting changes in student knowledge, skills, attitudes, and/or beliefs. (p. 799)

Lo (2018) suggested that the pillars of *communication* and *learning* have already been addressed in recent FC research, but the grounding of the FC with the other pillars is necessary. Hence, Lo provided 10 recommendations for the design and implementation of the FC incorporating the six pillars with the support of several FC studies (see Table 2.1).

Table 2.1
Recommendations on the design and implementation of FCs based on Spector's (2016) six pillars of educational technology (Lo, 2018)

Pillars	Recommendations
Communication	1. Introduce the FC approach to students and obtain parental consent 2. Use cognitive theory of multimedia learning to inform the production of instructional videos
Interaction	3. Create a discussion forum for online interactions 4. Provide online quizzes on video lectures with computerized feedback
Environment	5. Provide human resources and technical resources to support FC practices 6. Adopt a school-/faculty-wide approach to FC practices
Culture	7. Cultivate a classroom culture for learner-centered instruction
Instruction	8. Utilize established models as the framework for FC design
Learning	9. Provide optimally challenging learning tasks with instructor's guidance 10. Use peer-assisted learning approaches during class meetings

Note. Adapted from "Grounding the flipped classroom approach in the foundations of educational technology" by C. K. Lo, 2018, *Educational Technology Research and Development, 66,* p. 799.

There remains a lack of empirical studies on the efficacy of the proposed foundation on educational technology in FCs, but the 10 recommendations can trigger potential improvement in the design and incorporation of FCs in real practice (Lo, 2018).

2.4.6 Implications of the Review of Theoretical Frameworks for this Study

Concerning SCLT, interactive activities with constructivist approaches have often been found to be effective in science education in Hong Kong (e.g., Yip, 2001; Yip & Cheung, 2004). However, it is still not known whether or to what extent the integration of these student-centered learning activities, such as technology-enhanced POE strategy and inquiry-based learning in a flipped science classroom, benefit students, suggesting further investigation is needed.

Moreover, according to a quasi-experimental research conducted by Jensen et al. (2015) with an undergraduate biology course, the FC approach was not found to be more effective in improving student exam performance in terms of low-level recall of facts, high-level application problems and scientific reasoning, nor attitudes toward the course when compared with a non-flipped counterpart integrating the same in-class active-learning strategies. As proposed by the researchers, the reason the students' learning improved was likely due to the active-learning style of instruction rather than flipping the classroom (Jensen et al., 2015).

Undoubtedly, this proposition should be further tested empirically in another variety of classroom (Jensen et al., 2015), such as in a secondary school. Research design regarding comparing and evaluating an additional control group of traditional non-FC that consists of the same in-class active-learning strategies should be considered in this research.

On the other hand, this research recognizes the importance of managing SDT and CLT in the design of an FC to make science learning in the FC more motivating, manageable, and achievable (Abeysekera & Dawson, 2015). For instance, incorporating challenging and motivating activities in the pre-class technology-enhanced POE by using innovative mobile loggers and scientific inquiry-based learning in the in-class face-to-face interaction, as well as using self-authorized videos of restricted duration (five minutes) to prevent demotivation. However, in-depth evaluation regarding hypotheses related to SDT or CLT on student learning in flipped science classrooms is unnecessary because of the existing evidence from similar FC research findings in secondary science education (e.g., Zainuddin, 2018).

Regarding SRL theory, self-regulation plays a critical role in the FC because students and teachers are physically separated, and there will be no teacher present physically during student out-of-class online learning (Barnard et al., 2009). Although some FC research concerning SRL has been conducted in higher education, no empirical study has assessed students' SRL in a flipped science classroom in secondary school. Therefore, SRL theory was grounded in the FPOE for investigation.

Furthermore, Schraw et al. (2006) suggested that student-centered learning strategies are possibly ideal approaches for the promotion of student learning in science with the support of empirical evidence. A modified FC employing out-of-class technology-enhanced POE and in-class inquiry-based learning is likely be a good approach to help students to learn science in a self-regulated way with the foundation of learning theories. However, we still do not know how students learn with their SRL strategies, nor how these strategies help them to improve their academic achievements in modified FCs. Therefore, this research is timely for addressing these questions.

Finally, this research adopts Lo's (2018) recommendations for a comprehensively robust design and incorporation of FC in K-12 science education in real practice (see Appendix 1)

2.5 Pedagogical Frameworks

To plan and implement an FC in real practice, the arrangement of learning activities in both the out-of-class individual space and the in-class group space should be considered by utilizing some recognized and effective pedagogical frameworks. The results from the literature review regarding the FC suggest there is a lack of agreement about the best mixture for the out-of-class and in-class learning pedagogies. There is also a shortage of clarification regarding which in-class activities could be advantageous for constructivist learning in FCs (Kim, Jung, de Siqueira, & Huber, 2016). Hence, the following section describes the pedagogical frameworks that have been employed in primary and secondary education and examines which framework is the most suitable for flipping a science classroom in this study.

2.5.1 Bloom's Revised Taxonomy

Bloom's revised taxonomy has been proposed in some of the FC literature (e.g., Bergmann & Smith, 2017; Lo, 2018; Sams & Bergmann, 2013; Talbert, 2017). This approach is a cumulative hierarchical framework that consists of a taxonomy of learning objectives: remember, understand, apply, analyse, evaluate, and create (Anderson & Krathwohl, 2001). In a TC, a mastery of learning objectives at the lower level is required before mastering higher-level learning (Lo, 2018). In the FC, however, learning tasks relating to the lower level of Bloom's revised taxonomy (i.e., remember and understand) can be delivered in the form of instructional videos in the individual space outside the classroom, meaning that more classroom time can be spent on the more difficult cognitive tasks relating to the upper level of Bloom's revised taxonomy (i.e., apply, analyse, evaluate, and create), as illustrated in Figure 2.4 (Sams & Bergmann, 2013; Wang, 2017).

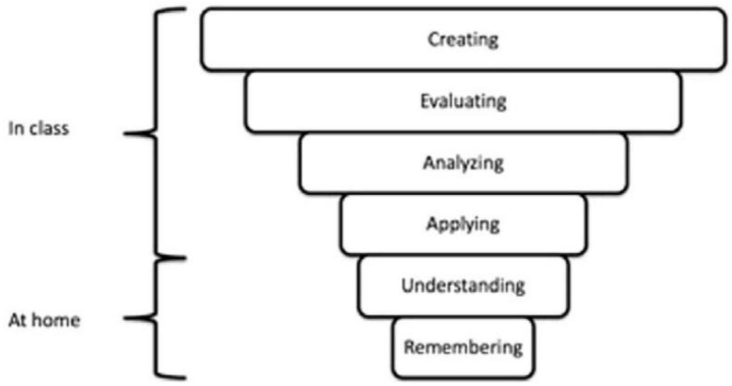

Figure 2.4. Bloom's revised taxonomy in the FC

Reprinted from "Overcoming barriers to 'flip': building teacher's capacity for the adoption of flipped classroom in Hong Kong secondary schools," by T. Wang, 2017, *Research and Practice in Technology Enhanced Learning, 12(6),* p. 2.

Bergmann and Sams (2012) pioneeringly created, in 2008, an FC called the flipped mastery classroom for the teaching of high school chemistry. In the flipped mastery classroom, students need to learn the content of the subject in a pre-defined manner (i.e., lower level of Bloom's taxonomy) by watching a video and participating in the in-class activities. With adequate proficiency, students can advance to the next level of knowledge content by watching another video and participating on other activities progressively (i.e., higher level of Bloom's taxonomy). Such a learning in the flipped mastery classroom is regarded as personalized and differentiated learning strategies for individual needs (Bergmann & Sams, 2012). Moreover, teachers in the flipped mastery classroom can "see who might need to conduct a lab, who needs to take an exam, and who needs remediation on a particular objective" (Bergmann & Sams, 2012, p. 53). Although the researchers reported that the students' academic achievements improved, the learning in the flipped mastery classroom should still be regarded as a teacher-centered approach because most of the learning objectives were defined by the teacher not the students.

On the other hand, Wong and Cheung (2015) stressed that Bloom's revised taxonomy can only classify the intended learning outcomes or objectives of a specific lesson rather than its contents or learning activities, suggesting that consideration of the level of interaction with students should be made. The researchers proposed a 4S decision matrix using the cognitive level from Bloom's revised taxonomy and the level of interaction for arranging learning activities in the FC (see Figure 2.5).

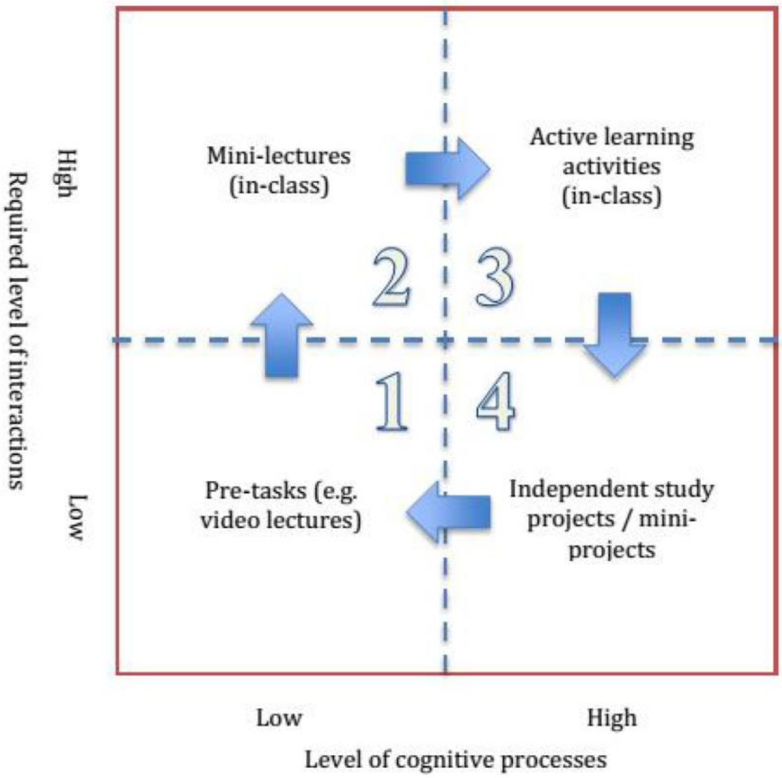

Figure 2.5. 4S decision matrix for arranging learning activities in the FC

Reprinted from G. K.W. Wong and H. Y. Cheung (2015), "Flipped classroom for student engagement in higher education." Hawkins (Ed.), *Student engagement: Leadership practices, perspectives and impact of technology* (p. 79). New York: Nova Science Pub Inc.

According to this 4S decision matrix, the sequence of the learning activities is recommended following the direction of the arrow in Figure 2.5. Students should first participate in Stage 1, which consists of pre-tasks at home to obtain some fundamental knowledge of the new topic. When students come to the lesson in Stage 2, a mini lecture is provided to extend the pre-tasks or seek initial feedback from the students' preparation. Both Stages 1 and 2 only involve remembering or a basic understanding of the facts as the intended learning outcomes. Then, students engage in face-to-face active-learning activities, such as lab exercises and collaborative problem-based activities, to develop higher-order thinking that meets the intended learning outcomes of analyzing, evaluating, and creating. Stages 2 and 3 may repeat and reverse a few times if necessary. Finally, in Stage 4, students complete some follow-up individual tasks to consolidate what they have learned previously to meet a higher ILO independently.

This 4S decision matrix undoubtedly offers a more detailed guideline for arranging student learning activities in the FC than the basic Bloom's revised taxonomy. Many FC interventions in K-12 education, including the conventional and modified ones, consist of pedagogies following this 4S decision matrix (e.g., Lo et al., 2018) despite an absence of explicit grounding of this 4S model in the research.

Another example of FC research on employing and refining Bloom' revised taxonomy for the design of FCs is the flipped social inquiry learning carried out in secondary school liberal studies in Hong Kong (Jong, 2017). This FC was designed based on Stripling's (2008) model of guided social inquiry learning, which consists of the lower cognitive learning phases of Bloom's revised taxonomy (*Connect*, *Comprehend* and *Express*), which involve the remembering and understanding of societal issues during the lessons (Jong, 2017). The flipped social inquiry learning also contains higher cognitive learning phases of Bloom's revised taxonomy, including *Wonder*, *Construct* and *Reflect*, which involve the application, analysis, and evaluation of the resources out of the lessons (Jong, 2017). All the learning phases were arranged in a sequence of Connect, Wonder, Comprehend, Construct, Express, and Reflect (Jong, 2017). The findings suggested that the flipped social inquiry learning promoted student knowledge acquisition and self-efficacy, to different degrees, among Grade 11 students with different (high, moderate, and low) academic abilities when compared with a conventional approach (Jong, 2017).

2.5.2 5-E Instructional Model

Another framework for helping the design of the FC is the 5-E instructional model (Bybee et al., 2006). This model of constructivist teaching and learning (Boddy, Watson, & Aubusson, 2003) is derived from numerous instructional historical models (e.g., Herbart's instructional model) and contains five sequential phases for lesson planning: *Engagement*, *Exploration*, *Explanation*, *Elaboration*, and *Evaluation*.

Jensen et al. (2015) incorporated this 5-E instructional model into their university biology classes. The model consists of a flipped approach in which the first three phases – *Engage*, *Explore*, and *Explain* – were implemented prior to class to facilitate content attainment via an online course-management system followed by in-class *Elaborate* and *Evaluate* phases on concept application. The control group consisted of identical resources but with the first three phases arranged during the lessons and the last two phases organized after the lesson through the online course-management system, similar to a conventional classroom. The researchers concluded that the 5-E instructional model produced active and constructivist learning in both FCs and TCs in higher education, though no significant difference in learning gains between the groups was found (Jensen et al., 2015). Lo (2018) summarized the five phases that Jensen et al. (2015) adopted in their FC research and recommends the following instructional pillar for the design of the FC (see Table 2.2).

Table 2.2
Possible pedagogical framework for the FC with 5-E instructional model (Lo, 2018)

Phase	Description
Out of class	
Engagement	The instructor uses learning activities to elicit students' curiosity and activate the prior knowledge required to learn the new topic
Exploration	Students gain experiences related to the learning items through activities such as preliminary investigation
Explanation	Based on students' experiences of engagement and exploration, the instructor introduces new knowledge and skills to their students
In class	
Elaboration	The instructor reinforces students' understanding and improves their skills by offering additional activities. The students are required to apply what they have learned to solve novel problems
Evaluation	The students assess their own understanding and ability. The instructor evaluates the students' learning progress and their learning outcomes

Note. Reprinted from "Grounding the flipped classroom approach in the foundations of educational technology" by C. K. Lo, 2018, *Educational Technology Research and Development, 66,* p. 805.

Furthermore, Lo (2017) proposed a cyclical pedagogical model that performs the *Engagement*, *Exploration*, *Explanation*, and *Evaluation* phases all outside the classroom, with the *Elaboration* and *Evaluation* phases, together with *Engagement* phase, in-class as the main focus of the teaching and learning for history education (see Figure 2.6). The revision of a linear 5-E instructional model into a cyclical one responds to the need for *Evaluation* being essential for assessing student online learning outside the classroom, and *Engagement* is necessary to provide feedback and recall student preparation for the in-class activities, such as critiquing and elaborating arguments, writing tasks, and assignments, as well as evaluating student work and presentation (Lo, 2017).

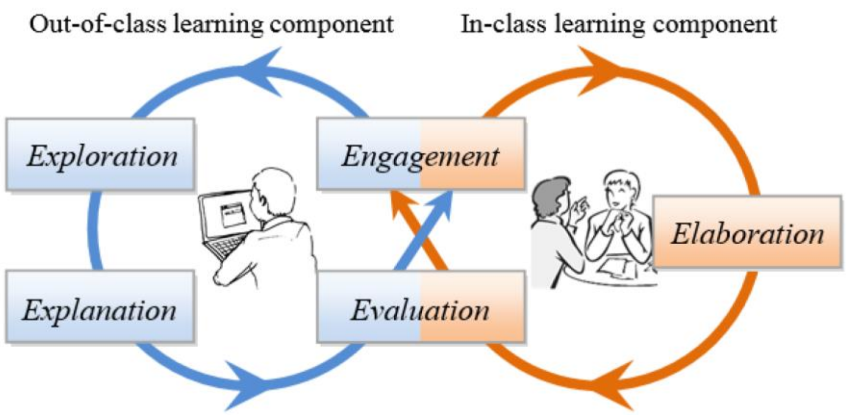

Figure 2.6. A cyclical 5-E instructional model for the FC

Reprinted from "Toward a flipped classroom instructional model for history education: A call for research," by C. K. Lo, 2017, *International Journal of Culture and History, 3(1),* p. 40.

Further research is required to examine the effectiveness of using this cyclical 5-E instructional approach for the design of FCs in history education (Lo, 2017).

Moreover, an inverted version of the FC, called productive-failure-based FC (PFFC), was proposed and implemented in a Grade 7 mathematics classroom in Hong Kong by Song and Kapur (2017). In the PFFC, students first participated in solving mathematical problems in the lesson, which involved the 5-E instructional approach of (a) engaging, (b) exploring, and (c) explaining. Then, the students consolidated their concepts by watching instructional videos after the lesson. The findings suggested that the students' conceptual knowledge and problem-solving skills in mathematics significantly improved (Song & Kapur, 2017).

2.5.3 Merrill's First Instruction Model

Kim et al. (2016) used Merrill's (2002) first principles of instruction model as a pedagogical framework in their case study of a student-centered laboratory in a graduate level public health FC. Merrill's model contains (1) activation of prior experience, (2) demonstration of skills, (3) application of skills, (4) integration of these skills into real-world activities, and (5) problem-centered activities (Merrill, 2002). Through classroom observations, a student survey, and an instructor interview, the researchers found that the students were highly engaged in the learning activities related to demonstration and application (Kim et al., 2016). However, the students barely participated in the higher-order learning activities that lacked challenging problem-based activities (Kim et al., 2016).

In Hong Kong, Lo and Hew (2017) investigated the feasibility of using Merrill's (2002) model to design their FC for a Grade 12 mathematics class in a secondary school. The results revealed that this approach helped enhance student mathematics achievement regardless of ability (Lo & Hew, 2017). Figure 2.7 illustrates the design framework of the FC that incorporates the four phases of Merrill's (2002) model.

Furthermore, a larger-scale quasi-experimental research on an FC with the model was carried out on Grades 8–12 students in four subjects (Chinese language, mathematics, physics, and information and communication technology) in secondary schools (Lo et al., 2018). The findings revealed positive effects of the FC on improving student achievements in three of the subjects: Grade 9 mathematics, Grade 9 physics, and Grade 8 Chinese language.

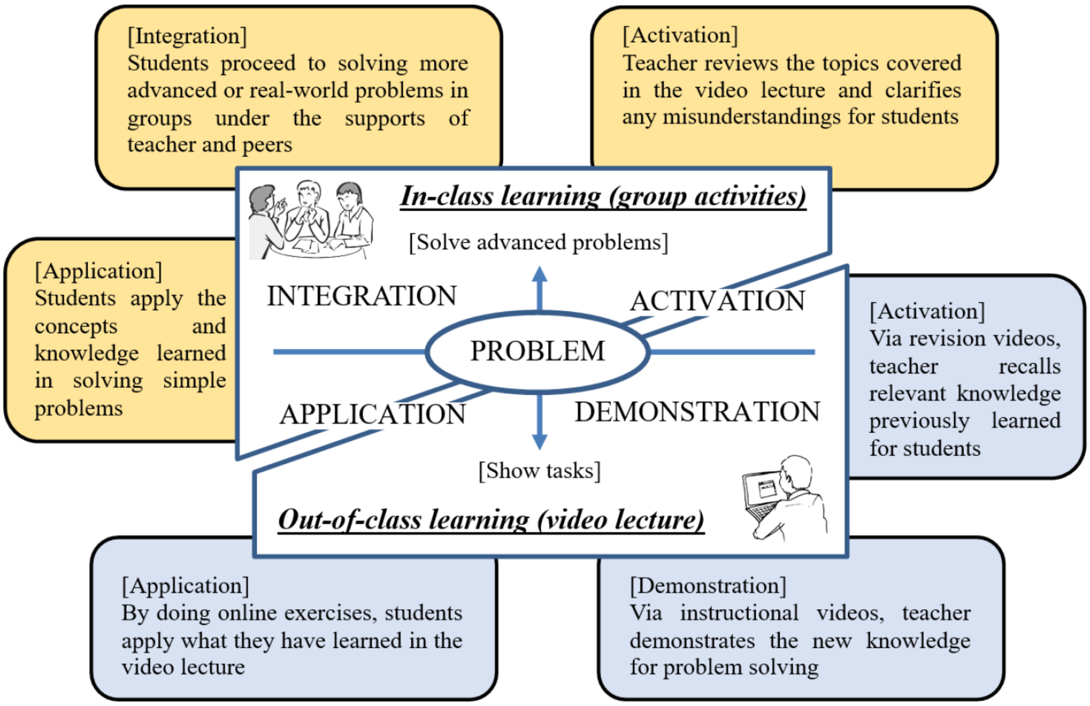

Figure 2.7. The pedagogical framework of an FC incorporating Merrill's (2002) first principles of instruction

Reprinted from "Using "First Principles of Instruction" to design secondary school mathematics flipped classroom: The findings of two exploratory studies," by C. K. Lo and K.F. Hew, 2017, *Studies. Educational Technology & Society, 20 (1),* p. 224.

2.5.4 Implications of the Review of Pedagogical Frameworks for this Study

Considering Bloom' revised taxonomy in the pedagogical design of an FC, the lower level of cognitive learning is often suggested for the out-of-class online environment without guidance from teachers, whereas the higher level of interactive learning is recommended for class time. However, there remains a lack of research findings and literature evidence discourse regarding the efficacy of shifting higher-level learning activity, which is often regarded as a challenging task, to the out-of-class preparatory phase of the FC. Hence, this research should consider Bloom's revised taxonomy for the design of a modified FC, incorporating a higher level of cognitive learning (i.e., moving the technology-enhanced POE strategy to the pre-lesson stage).

The development of the in-class inquiry-based learning (i.e., the scientific inquiry) should also aim to achieve a higher-order level of learning as with the intended learning outcomes.

Merrill's (2002) model has several features in common with the 5-E instructional model. For instance, the activation phase of the first instruction model contains the same notion as the *Engagement* phase of the 5-E instructional model. Both phases encourage teachers to organize activities about recalling and activating students' prior knowledge, which is required for learning a new topic. On the other hand, a major difference is that Merrill's model emphasizes the engagement of solving problems that can be found in the real world in in-class activities, whereas there is no such focus in the 5-E model. Therefore, the 5-E instructional model is more suitable for this research as the technology-enhanced POE and scientific inquiry-based activities need not be developed solely based on real-life problems; instead, they can be constructed for the studying, investigating, and explaining of the natural world (Anderson, 2002).

Regarding K-12 science education, extensive empirical research has already revealed that the 5-E instructional model has significant positive effects on student attitude and interests toward science (e.g., Akar, 2005), mastery of subject matter (e.g., Coulson, 2002), and scientific reasoning (Boddy et al., 2003) in learning science (Bybee et al., 2006) outside the FC context. Taken together with the evidence from the aforementioned FC studies with the 5-E components that successfully improved student learning in different K-12 disciplines, this research incorporated the modified 5-E instructional model (Lo, 2017) into the flipped classrooms. Table 2.3, below, summarizes different FC empirical studies based on the mentioned frameworks in a K-12 context.

Table 2.3

A summary of the FC empirical studies based in different theoretical and pedagogical frameworks in K-12 education

Research design / Country	Grade and location	Subject	Sample size / group / duration	Theoretical framework for FC: SCLT	SDT	CLT	SRLT	SSP	Pedagogical framework for FC: Bloom's revised taxonomy: R1	U2	A3	A4	C5	5-E instructional model: E1	E2	E3	E4	E5	Merrill's first instruction
FMC (Bergmann & Sams, 2012)	10 US	Chemistry	FC						VW*		LS, D, HA*								
PIFL (Faulkner & Green, 2015)	9–10 US	Math	FC/TC	√					VW, Q		GD (PI)								
EBBFL (Hwang & Lai, 2017)	4 Taiwan	Math	24(EBBFL)/21(TFC) 4 weeks	√					VW		GD, PS								
FC (Sergis et al., 2018)	8–10 Greece	ICT, Math, Humanities	63(FC) / 65(TC) 8 weeks	√	√				VW, Q		HA								
GFC (Zainuddin, 2018)	9–10 Indonesia	Science	27(GFC)/ 29 (TFC) 12 weeks	√	√				VW, GQ		GD								
CTML (Bhagat et al., 2016)	8–9 Taiwan	Math	41(FC)/41 (TC) 6 weeks	√		√			VW		GD, PS								
SRLFC (Lai & Hwang, 2016)	4 Taiwan	Math	20 (SRLFC)/24 (TFC)	√			√		VW, WS		GD, PS, SE								
FSIL (Jong, 2016)	11 Hong Kong	Liberal studies	108 (FC) / 107 (TC) 9 days	√					VW*		GD, WS, SP, RP*		VC*						
PFFC (Song & Kapur, 2017)	7 Hong Kong	Math	(PFFC) / (TFC)	√					VW		VW, GD, PS			√	√	√			
FC (Lo et al., 2018)	9–10 Hong Kong	Math, ICT, physics, Chinese	11- 119 (FC) /11-125 (TC)	√					VW, Q, BR, ML		PS								√

√ = Theory adopted or discussed explicitly in the literature * = level of learning adopted or discussed explicitly in the literature

Research design: = FMC flipped mastery classroom, PIFL = peer-instruction flipped classroom, EBBFL = e-book-based flipped classroom, GFC = gamified flipped classroom, CTML = cognitive theory of multimedia

learning, FSIL = flipped social inquiry learning, PFFC = productive-failure flipped classroom, FC = flipped classroom, TC = traditional classroom, TFC = tradition flipped classroom
Theoretical theory: SCLT = student-centered learning theory, SDT = self-determination theory, CLT = cognitive load theory, SRLT = self-regulated learning theory, SSP = Spector's six pillars
Bloom's revised taxonomy: R1 = remember, U2 = understand, A3 = apply, A4 = analyze, C5 = create, E1 = engagement, E2 = exploration, E3 = explanation, E4 = elaboration, E5 = evaluation
Learning activity: LS = lab station activities, D = demonstration, HA = hands-on activities, VW = video-watching, VC = video-creating, Q = quiz, GD = group discussions, PI = peer instruction, RP = role playing, WS = web searching, SP = student presentation, PS = problem-solving, GQ = gamification quiz, WS = completing worksheets, SE = self-evaluation and reflection, BR = brief reviews of out-of-class learning, ML = mini-didactic lectures

2.6 A Scoping Review of Flipped Classrooms in K-12 Science Education

2.6.1 Rationale

To form a clear understanding of how educators have designed and implemented the FC approach, meta-studies or systematic reviews of the existing literature are necessary (Abeysekera & Dawson, 2015; Lo & Hew, 2017). However, most of the existing systematic reviews are restricted to higher education (e.g., Bishop & Verleger, 2013; O'Flaherty & Phillips, 2015). Some reviews are also limited to disciplines only offered at university, such as health professions education (Hew & Lo, 2018), medical courses (Lin & Hwang, 2019), nurse education (Bernard, 2015; Betihavas et al., 2016), and computer science education (Giannakos et al., 2014). We can only identify one scoping literature review that specifically targeted K-12 education (Lo & Hew, 2017), with most scoped studies being confined to mathematics education. Furthermore, because the flipped learning approach remains under-evaluated and under-theorized (Abeysekera & Dawson, 2015), it is necessary to conduct a review to determine (a) how science teachers design their FC in terms of their theoretical and pedagogical considerations; (b) the efficacy of flipped interventions on student learning in science; and (c) the challenges of flipping science courses in a K-12 context.

2.6.2 Method

In this scoping review of FC in K-12 science education, a rigorous and reliable five-stage framework (Arksey & O'Malley, 2005) was adopted to scope the research (O'Flaherty & Phillips, 2015). The five stages of Arksey and O'Malley's (2005) framework are as follows: (1) identifying the initial RQs; (2) identifying relevant studies; (3) selecting studies; (4) charting the data; and (5) collating, summarizing, and reporting the results.

First, the initial RQs of this scoped review are as follows:

(a) What are the designs of the FC, including the details of in-class and out-of-class activities and the grounded frameworks in K-12 science education?

(b) What are the impacts of FC interventions on student learning outcomes in K-12 science education?

(c) What are the challenges that teachers and students face regarding the teaching and learning of science with the FC approach in K-12 science education?

Second, to identify relevant studies as comprehensively as possible (Lo & Hew, 2017; O'Flaherty & Phillips, 2015), seven electronic databases were searched: (a) Academic Search Ultimate, (b) ERIC, (c) Education Research Complete, (d) Education Full Text (H.W. Wilson), (e) Teacher Reference Center, (f) British Education Index, and (g) Library, Information Science & Technology Abstracts. In addition, the reference lists of identified articles, as suggested by O'Flaherty and Phillips (2015) and Lo (2017), were searched to find any other related primary sources. The following key terms were used in this search: (flip* OR invert*) AND (class* OR learn*) AND (science OR physics OR chemistry OR biology OR STEM) AND (Elementary OR primary OR secondary OR high school OR middle school OR K12). This search provided broad coverage of the available literature (Arksey & O'Malley, 2005). As a result, common phrases that corresponded to FCs (e.g., inverted learning, FC, inverting a class, and flipping a lesson), science-related subjects (e.g., science and biology), and K-12 education (e.g., kindergarten, primary school and secondary education) could be identified.

Third, to select the studies, inclusion and exclusion criteria were developed (see Table 2.4). To include studies with vigorous methodologies and reliable findings, the articles had to have been published in peer-reviewed journals. The period of the search was restricted from January 2012 to February 2020 (the time of writing) because few papers concerning FC were published prior to 2012 (Giannakos et al., 2014). There was no restriction on the use of language regarding the research location, but the reporting of the studies was limited to English. In addition, the studies had to be empirical research that reported an implementation of FC with learning outcomes in K-12 science education; hence, numerous studies on the use of FCs in science disciplines in the higher education sector were excluded. Furthermore, the FC had to satisfy Bishop and Verleger's (2013) definition of FC as the use of instructional videos to teach content knowledge in out-of-class time and face-to-face interactive learning activities in the classroom.

Table 2.4
Inclusion and exclusion criteria for selection

Criteria	Inclusion	Exclusion
Definition of FC	FC must make use of instructional videos to teach content knowledge in out-of-class time and face-to-face learning activities in the classroom.	FC did not include instructional videos to teach knowledge content in out-of-class time or did not have face-to-face learning activities.
Context	Studies must involve FC in the science subject in K-12 education (kindergarten, primary, and secondary schools).	Studies were outside K-12 science education, such as science in higher education, mathematics in primary school, etc.
Study focus	Studies must report empirical findings including effects on student learning.	Studies did not investigate any aspects of learning outcomes.
Period of search	January 2012 to February 2020.	Studies were outside these dates.
Type of articles	Studies published in peer-reviewed journals.	Studies were not peer-reviewed.
Language	English	Non-English

The search terms identified 358 peer-reviewed articles as of February 14, 2020. By reviewing the titles and abstracts, many articles were found to be irrelevant. These articles were primarily associated with the research on FC in higher education, studies regarding another meaning of *flip* in science (e.g., the inquiry-based activity of bottle flipping in science classrooms), and literature on FC without empirical findings. Moreover, numerous articles were excluded as they were duplicated across different databases. In addition, another five records were identified by searching reference lists from previously identified articles, as well as two records traced from other reviews of FC that were not limited in their studies to the context of higher education (i.e., Lo & Hew, 2017; Zainuddin & Halili, 2016; Zainuddin et al., 2019). Twenty-five full-text articles were assessed for eligibility, with 10 excluded for inappropriate context and study focus. Fifteen articles were finally selected for the scoping review. Figure 2.8 illustrates the selection process of articles based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA; Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009).

Following the identification of the target studies, data extraction and analysis were conducted. To ensure the validity of the data extracted, in-depth and lengthy content analysis (Creswell, 2012) was performed in a step-by-step manner to extract and categorize the data from the scoped articles. The categorization of the data into (a) overview of the research, (b) the FCs' designs, (c) the effects of the FCs on student learning, and (d) the FCs' challenges based on existing scoping reviews (e.g., Betihavas et al., 2016; Lo & Hew, 2017; O'Flaherty & Phillips, 2015; Zainuddin & Halili, 2016; Zainuddin et al., 2019). The extracted data were finally checked, and the grouping and clustering involved in the tables were also validated by the principal supervisor to improve the validity of the extracted and synthesized data.

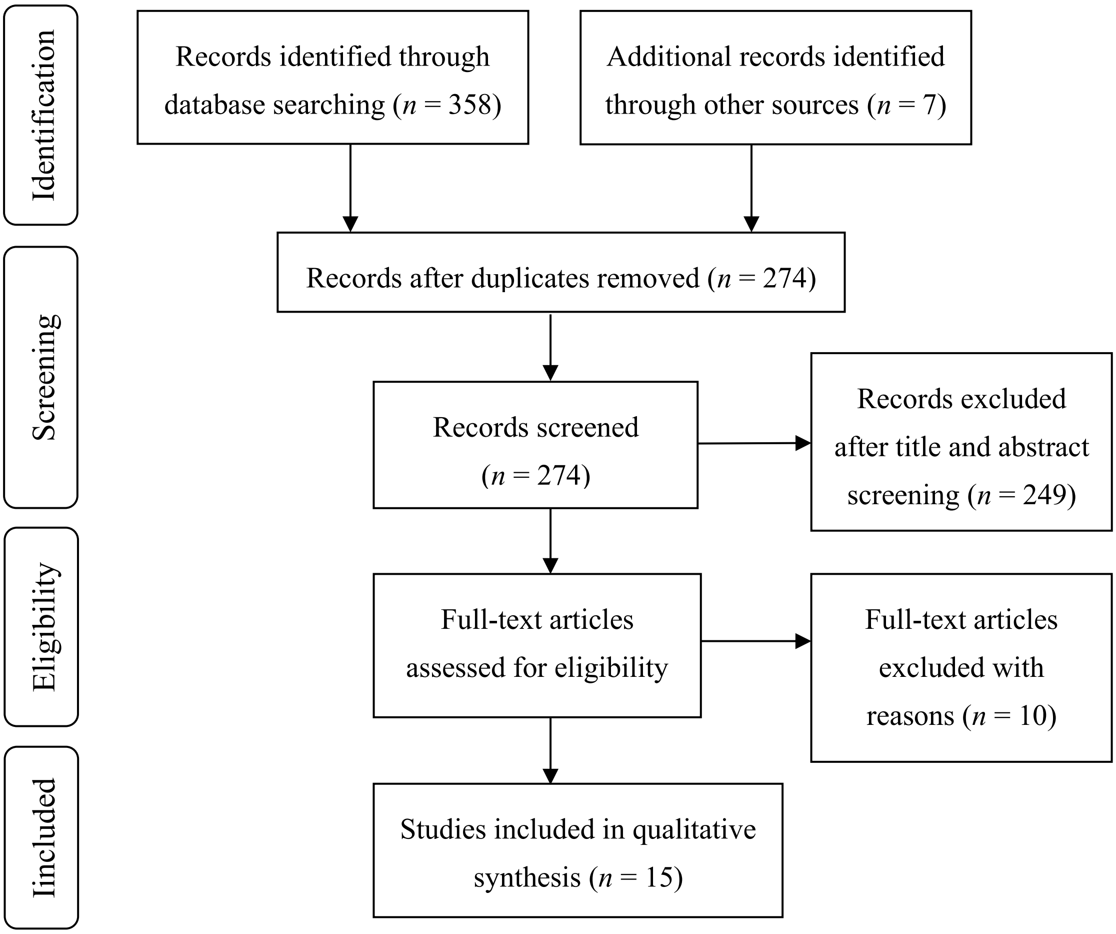

Figure 2.8. The selection process of articles based on PRISMA

An overview of the included studies was provided regarding author, year, location of the study, context, sample size, and research design (see Table 2.5). The design of each FC and its impacts and challenges are summarized in Tables 2.6 to 2.8. An elaboration of the findings is provided in the following section (2.6.3).

Table 2.5
An overview of the included studies regarding FC in K-12 science education

Study (author and year)	Location of study	Context (level and subject)	Sample size	Research design (duration)
Atwa et al. (2016)	Palestine	Grade 11 Physics	FC (57)/TC (56)	$^{P\text{-}P}$QE (1 topic)
Camiling (2017)	Philippines	Grade 2 STEM	FC (12)/TC (12)	$^{P\text{-}P}$QE (2 weeks)
Çetinkaya (2017)	Turkey	Grade 7 Science	WBAFC (37)/TFC (37)	$^{P\text{-}P}$QE (3 weeks)
Gariou-Papalexiou et al. (2017)	Greece	Grade 10 Biology	FC (17)	$^{P\text{-}P}$NE, AR (1 topic)
Kettle (2013)	UK	Aged 16–18 Physics	FC (12)	NE (appeared to be 1 semester)
Leo and Puzio (2016)	US	Grade 9 Biology	FC (42)/TC (29)	$^{P\text{-}P}$QE (appeared to be 2 topics)
Lo et al. (2018)	Hong Kong	Grade 9 Physics#	FC (119)/TC (125)	^{P}QE (10 weeks)
Olakanmi (2017)	Nigeria	Aged 13–14 Chemistry	FC (33)/TC (33)	$^{P\text{-}P}$QE (3 weeks)
Schultz et al. (2014)	US	Grade 10–12 Chemistry	FC (29)/TC (32)	^{P}QE (4 months)
Sezer (2017)	Turkey	Grade 6 Science	FC (35)/TC (33)	$^{P\text{-}P}$QE (2 weeks)
Slemmons et al. (2018)	US	Grades 7–9 Chemistry	FC-S (77.84)/FC-L (76.07)	^{P}QE (2 topics)
Sookoo-Singh and Boisselle (2018)	Trinidad and Tobago	Aged 14–15 Chemistry	FC (27)	$^{P\text{-}P}$NE, AR (6 weeks)
Stratton et al. (2020)	US	Grade 7 Science	FC (73)/TC (81)	$^{P\text{-}P}$QE (3 weeks)
Yousefzadeh and Salimi (2015)	Iran	Grade 7 Science#	FC (25)/TC (25)	^{P}QE (8 weeks)
Zainuddin (2018)	Indonesia	Aged 15–16 Science	GFC (27)/TFC (29)	^{P}QE (12 weeks)

= multi-disciplinary study with other subjects, FC = flipped classroom, TFC = traditional flipped classroom, GFC = gamified flipped classroom, WBAFC = web-based assist flipped classroom, TC = traditional classroom, NE = non-experiment, QE = quasi-experiment, AR = action research, $^{P\text{-}P}$ = pre-test and post-test, ^{P} = post-test

2.6.3 Findings

This review scoped 15 studies from 11 countries, including four from the US, two from Turkey, and one from each of the following regions: Greece, Hong Kong, Indonesia, Iran, Palestine, Philippines, Nigeria, Trinidad and Tobago, and the United Kingdom (UK). The FC studies were employed in the contexts of physics (n = 4), chemistry (n = 4), biology (n = 2), science (n = 4), and STEM (n = 1). This section discusses the findings of the studies, including the designs of the FCs, their impacts on student science learning, and related challenges.

2.6.3.1 The Designs of Flipped Classrooms in K-12 Science Education

Several researchers (e.g., Abeysekera & Dawson, 2015; Bishop & Verleger, 2013) have mentioned that it is vital to ground theoretical and pedagogical frameworks in the FC's design and implementation. However, less than half of the scoped studies (*n* = 7) employed a solid framework in the design and implementation of their FCs.

Regarding the 15 yielded studies, all included a pre-class video-watching activity (*n* = 15), meeting the inclusion criteria for FC based on Bishop and Verleger's (2013) definition. In addition to watching instructional videos prior to lessons, several learning activities were also identified in the K-12 flipped science classroom. These activities were quizzes (*n* = 5), note-taking (*n* = 4), online follow-up exercises (*n* = 1), studying from text-based (*n* = 2) and web-based materials (*n* = 1), online discussion (*n* =1), and reflection (*n* =1). In terms of in-class learning, group discussions (*n* = 6), problem-solving (*n* = 5), and brief reviews of online content, including brainstorming and question and answer (Q&A) sessions on videos (*n* = 4) were the main learning activities found in the studies. Regarding after-lesson work, only one study in the review allowed students to conduct self-evaluation. Table 2.6, below, illustrates the details of the design of the FCs in this review.

Table 2.6
Designs of the FCs in K-12 science education studies identified from the review

Study (author, year, location)	Grounded framework	Pre-class learning activities	In-class learning activities	Post-class learning
Atwa et al. (2016) Palestine		Watch videos, answer short quizzes in Blendspace, discuss on Facebook.	Q&A, clicker poll on videos, active-learning strategies (e.g., research projects).	
Camiling (2017) Philippines	5-E instruction model	Watch (online/CD) videos, take notes, and propose questions in	Prepare questions for group discussions on videos, perform	

		notebooks.	application activities, answer formative assessment.	
Çetinkaya (2017) Turkey	Assure instruction-al design model	Watch videos and view web-assisted materials.	Perform cooperative learning, complete web-assisted measurement and evaluation activities and quizzes.	
Gariou-Papalexiou et al. (2017) Greece	Bloom's taxonomy	Watch videos on content and experiment via LAMS.	Peer discussions, clarify student misconceptions.	Student self-evaluation.
Kettle (2013) UK		Watch videos via Moodle, take notes.	Note-taking, problem-solving.	
Leo and Puzio (2016) US		Watch videos and complete quizzes via Moodle.	Active and interactive learning includes projects, laboratories.	
Lo et al. (2018) Hong Kong	Merrill's first instruction	Watch videos, complete online follow-up exercises.	Brief review of out-of-class learning, mini lecture, problem-solving.	
Olakanmi (2017) Nigeria		Watch (online/DVD) videos, take notes.	Collaborative inquiry-based learning.	
Schultz et al. (2014) US		Watch screencast videos (10–15 mins), complete reflection in Google Forms.	Five-minute review of video content, discussion, problem-solving.	
Sezer (2017) Turkey		Watch (CD) videos and complete online quizzes.	Brainstorming, group discussion, and collaborative problem-solving.	
Slemmons et al. (2018) US	CLT, CTML	Watch videos, complete quizzes.	Interactive group learning (without detail).	
Sookoo-Singh and Boisselle (2018) Trinidad and Tobago	SCLT	Watch videos, study lecture notes, animations and PowerPoint presentations.	Conduct hands-on activities (without detail).	
Stratton et al. (2020) US		Watch videos, take notes, summarize the content, and propose questions.	Group discussion, practice tasks, and hands-on activities.	
Yousefzadeh and Salimi (2015) Iran		Watch videos.	Group discussions, collaborative problem-solving.	

Zainuddin (2018) Indonesia	SDT	Watch videos, complete gamified quizzes via iSpring Learn LMS.	Group discussions and student presentations.

LAMS = learning activity management system, LMS = learning management system, SCLT = student-centered learning theory, CLT = cognitive load theory, CTML = cognitive theory of multimedia learning, SDT = self-determination theory

2.6.3.2 The Impacts of Flipped Classrooms on Student Science Learning in K-12 Education

Most of the scoped studies evaluated student academic performance (n = 13), and several assessed student motivation (n = 4), engagement or participation in flipped learning (n = 6), and their attitudes toward their flipped learning (n = 6). We also found that very few studies investigated the efficacy of FC on the development of student scientific learning skills, such as SPS (n = 1). Among the 13 studies that evaluated student academic performance following a flipped learning intervention, nine revealed a positive effect on the efficacy of FC on student achievement, whereas numerous studies reported a non-significant result or mixed findings in their quantitative research between the flipped learning treatment group and the traditional learning counterparts (n = 4). There is also a limited investigation (n = 1) of the effect of FC on students with different learning abilities, suggesting more future studies are required. Table 2.7, below, lists the impacts of each FC on K-12 science education among the scoped studies.

Table 2.7
Impacts of FC on K-12 science education among the scoped studies

Study (author, year, and location)	Type of impacts	Impacts of FC on student science learning
Atwa et al. (2016) Palestine	Academic performance	Student achievement (post)scores in physics in FC were significantly better than those in TC.[AP]
Camiling (2017) Philippine	Skills	Students in FC had significantly higher basic process skills according to mean test scores than those in TC.[S]
Çetinkaya (2017) Turkey	Academic performance	Post-test results analysis revealed a positive significant difference in achievement for the students in WBAFC compared to those in TFC.[AP]
Gariou-Papalexiou	Academic	No significant difference between pre- and post-

et al. (2017) Greece	performance and engagement	tests on photosynthesis were reported.[AP] Qualitative results indicate that student time management in the classroom and involvement in the educational process were improved.[E]
Kettle (2013) UK	Academic performance and attitude	Mixed findings for student achievement.[AP] FC students considered in-class note-taking and problem-solving to be effective and enjoyable but watching videos to be ineffective and unenjoyable.[A]
Leo and Puzio (2016) US	Academic performance and attitude	Two quizzes and one post test demonstrated statistically significant gains in FC learning.[AP] The qualitative results suggest that students may have benefited from the active-learning strategies and enjoyed learning through FC.[A]
Lo et al. (2018) Hong Kong[#]	Academic performance and engagement	The levels of student achievement in physics were significantly higher in FC than those in TC.[AP] Teachers' comments recognized the benefits of student participation in out-of-class learning.[E]
Olakanmi (2017) Nigeria	Academic performance and engagement	Students' mean scores of conceptual understanding of the rate of chemical reactions in FC were significantly higher than those in TC.[AP] Qualitative findings suggest FC benefits students to encourage active learning through interactions with peers and teachers.[E]
Schultz et al. (2014) US	Academic performance and attitude	Grade 11 students in FC had significantly higher mean scores than those in TC for all eight assessments, gender difference was also significant (male > female).[AP] Most students perceived FC positively.[A]
Sezer (2017) Turkey	Academic performance, attitude, and motivation	The FC generated a larger increase in students' academic achievement scores and motivation scores in post-test compared with TC according to a two-way repeated-measures ANOVA.[AP, M] The result was supported by interviews with students. Interview findings revealed FC had a positive effect on student perceptions of the science course.[A]
Slemmons et al. (2018) US	Engagement	Students perceived that they had higher rates of retention of content and higher degrees of engagement and focus when learning from short videos.[E]
Sookoo-Singh and Boisselle (2018) Trinidad and Tobago	Academic performance, motivation, and attitude	Academic achievement was not significantly affected by FC.[AP] Motivation was positively and significantly affected by FC.[M] Most students perceived the positive effects of the FC intervention.[A]
Stratton et al. (2020) US	Academic performance, attitude, engagement, and motivation	ANOVA results revealed no differences in performance between students with different learning abilities in FC and TC.[AP] Student survey data indicated that most students enjoyed learning about science in FC, and the experienced increased engagement and motivation.

		A, P, M
Yousefzadeh and Salimi (2015) Iran#	Academic performance	Students' average scores of achievements in FC were significantly higher than those in TC.[AP]
Zainuddin (2018) Indonesia	Academic performance, motivation, and engagement	Two post-test scores in GFC were significantly higher than those in TFC.[AP] Most items in students' perceived competence (4 out of 5) and autonomy (5 out of 5) were significantly higher in GFC than those in TFC. Only one item of perceived relatedness was significantly different between GFC and TFC.[M] The GFC setting fostered better engagement.[E]

= multi-disciplinary study with other subjects, FC = flipped classroom, TFC = traditional flipped classroom, GFC = gamified flipped classroom, WBAFC = web-based assist flipped classroom, TC = traditional classroom, AP = academic performance, A = attitude, M = motivation, E = participation/engagement, S = skills

2.6.3.3 The Challenges of Flipped Learning Among Scoped Studies in K-12 Science Education

Several challenges, including student-related, faculty-related, and operation-related challenges, as categorized by Betihavas et al. (2016), are addressed in the scoped studies in this review. More than half of the 15 studies report different aspects of operation-related challenges in their FC interventions (n = 10). One of the most common operation-related challenges was the difficulty ensuring that students watched the instructional videos prior to the lesson (Gariou-Papalexiou, Papadakis, Manousou, & Georgiadu, 2017; Kettle, 2013; Lo et al., 2018; Slemmons et al., 2018; Sookoo-Singh & Boisselle, 2018; Yousefzadeh & Salimi, 2015). Limited infrastructure (Sezer, 2017), accidental malfunctioning of online platforms (Leo & Puzio, 2016), and problems accessing online videos (Gariou-Papalexiou et al., 2017; Kettle, 2013; Schultz et al. 2014; Sookoo-Singh & Boisselle, 2018) were also identified.

Regarding student-related challenges (n = 8), student reluctance to participate in out-of-class learning (Gariou-Papalexiou et al., 2017; Sookoo-Singh & Boisselle, 2018; Yousefzadeh & Salimi, 2015), initial struggles with familiarizing students with the FC (Atwa, Din, & Hussin, 2016; Olakanmi, 2017; Schultz et al., 2014), the long duration of videos, heavy workload, and a lack of out-of-class rapid support from teachers (Schultz et al. 2014; Stratton, Chitiyo, Mathende, & Davis, 2020) were identified.

Regarding the faculty-related challenges identified in the scoped studies (*n* = 5), they all suggested that more time and effort was needed for the teachers to design and implement the FC in practice, such as by preparing in-class student-centered lessons (Gariou-Papalexiou et al. 2017; Yousefzadeh & Salimi, 2015), and finding suitable instructional videos (Kettle, 2013; Lo et al., 2018; Sezer, 2017). Table 2.8 lists the comments about the challenges of flipped learning that were made in the scoped studies.

Table 2.8
The challenges of flipped learning among the scoped studies in K-12 science education

Study (author, year, location)	Category of challenges	Exemplary quotes on the challenges of FC in practice
Atwa et al. (2016) Palestine	Student-related	"It may take more than one semester for the students to get accustomed to the FLM and value it."
Camiling (2017) Philippines		
Çetinkaya (2017) Turkey		
Gariou-Papalexiou et al. (2017) Greece	Student-related & operation-related	"Some others [students] did not even get into the platform."
	Operation-related	"It was found that they had no access to a computer or the Internet at home."
	Faculty-related	Implementing the FC "demands more time and effort in order for the teacher to prepare the lesson."
Kettle (2013) UK	Faculty-related	"The searching for every video on every topic was a time-consuming process."
	Student-related & operation-related	"[Students] did not recall the key ideas, were not equipped for the problem-solving lesson and did not realize they were underprepared."
	Operation-related	"The school's 'net nanny' blocked all access to YouTube for students, and some videos could only be accessed from home."
Leo and Puzio (2016) US	Operation-related	"The school web interface, which promised to track student video usage, was not working properly."
Lo et al. (2018) Hong Kong#	Operation-related	"The challenge is to ensure that all of them [students] watched the videos before the lessons."

	Faculty-related	"It is difficult to find relevant videos that can also match the students' English standard."
Olakanmi (2017) Nigeria	Student-related	"Most of them [students] felt that the new approach was a bit challenging for them initially as it took them some time to find their ways around the material."
Schultz et al. (2014) US	Student-related & operation-related	"Negative features included the teacher being unavailable during video lectures, the videos were too long, missing a video and would get behind, missed classroom interaction, and technology issues. A unique negative issue reported was having two flipped classes created more homework."
Sezer (2017) Turkey	Faculty-related	"The preparation of the various electronic resources required for the application of the flipped classroom environment and the motivation of students is a very difficult job in the already busy professional life of teachers."
	Operation-related	"It is hoped that the flipped classroom environment supported by this technology will contribute positively to the outcome of this project and will improve students' learning. These studies on classroom environment are limited in number, and it is an issue not much explored in the literature on Turkey."
Slemmons et al. (2018) US	Operation-related	"Determining whether students actually watched videos was limited."
Sookoo-Singh and Boisselle (2018) Trinidad and Tobago	Operation-related	"Students faced problems accessing the materials."
	Student-related & operation-related	"Some students, even though they had access to the materials, did not complete the lectures at home."
Stratton et al. (2020) US	Student-related	"Students reported disliking having to wait for a response to questions [in out-of-class learning]."
Yousefzadeh and Salimi (2015) Iran#	Student-related & operation-related	"If the students don't want to watch the videos or complete the activities before the class, they will be unprepared to use their new knowledge during the class time."
	Faculty-related	"Teachers involved with flipped classes must be prepared for time-consuming and demanding work." "[FC] requires the teachers to guide students as they apply their new knowledge in the classroom."
Zainuddin (2018) Indonesia		

= multi-disciplinary study with other subjects, FC = flipped classroom, FLM = flipped learning model

2.6.4 Discussion

This review of 15 scoped studies suggests that the FCs in K-12 science education were effective at enhancing student motivation, engagement, and attitudes when compared with traditional learning counterparts. These findings correspond with the results of Lo and Hew's (2017) review of FC studies among various subjects in K-12 education, as well as those of other reviews of FC in higher education (Betihavas et al. 2016; O'Flaherty & Phillips, 2015; Giannakos et al., 2014; Seery 2015).

Regarding academic performance among science students, neutral results on the effectiveness of FCs were found, as several studies (n = 4) revealed no significant difference in student achievement between FCs and TCs (Gariou-Papalexiou et al., 2017; Kettle, 2013; Sookoo-Singh & Boisselle, 2018; Stratton et al., 2020). This finding echoes "the positive and at least neutral" (Lo & Hew, 2017, p. 1) results obtained in the recent review of FCs in K-12 education in various subjects other than science (Lo & Hew, 2017). However, unlike other educational contexts reviewed (e.g., mathematics in elementary school and information and communication technology in higher education), research on FCs in K-12 science education on the improvement of students' metacognitive skills, such as SRL, FC learning was insufficient. In addition, the evaluation of subject-specific achievements, such as SPS, was also limited in the FC studies on K-12 science education (n = 1; Camiling, 2017). This review also found that there was limited investigation (n = 1; Stratton et al., 2020) of the effect of FCs on students with different learning abilities.

Considering the designs of FCs among the scoped studies, all the studies included both pre-class video-watching and in-class face-to-face learning activities, but only one organized after-class activities for students to conduct self-evaluation (Gariou-Papalexiou et al. 2017). However, no significant impact on student achievement was found in the study that incorporated after-class evaluation, suggesting that future investigations of the exploitation of post-class follow-ups is necessary. In addition, several studies utilized an established theoretical or pedagogical framework (e.g., the 5-E instructional model employed in Camiling [2017] study) in the design and implementation of their FCs (n = 7). Five of these studies reported significant and positive impacts of their FC on students' gains in achievement. Nonetheless, we cannot draw a definitive conclusion about the most effective framework for FCs in K-12 science education due to the limited number of homogeneous studies scoped.

In terms of research methodology, most of the scoped studies employed a quasi-experimental design (n = 12), including (a) a post-score study between FC and TC (n = 3); (b) pre- and post-scores quasi-experiments between FC and TC (n = 7); (c) a post-score study between FC and TC (n = 1); and (d) pre- and post-scores quasi-experiments between modified FC and TFC (n = 1). Some of the studies only employed a single-group non-experimental design (n = 3) to investigate FC efficacy. To a certain extent, the variation in research design limits a valid comparison of the effectiveness of FCs on student achievement (Lo & Hew, 2017). Moreover, caution should be exercised when considering the two studies that compared student achievements between a modified FC and a TFC since the significant results obtained only indicate the efficacy of the factor under study, such as student-centered learning strategies, rather than flipping the classroom or not without the employment of a non-flipped TC as an additional control (Jensen et al., 2015). Another limitation of the review is that several scoped studies implemented the FC over a short period, ranging from one to three weeks (n = 9), suggesting that the significant effect on the improvement of student achievements may be due to the novelty effect (Clark 1983), improving student performance in the short term by introducing technology from the FC. Finally, there is a shortage of qualitative data on lesson observations for the in-class learning activities among the 15 scoped studies (n = 2; Gariou-Papalexiou et al., 2017; Olakanmi, 2017).

Regarding the challenges in the design and implementation of FCs, most of the difficulties that occurred in subjects other than science, such as mathematics (Lo & Hew, 2017), were also found in K-12 science education. The operation-related challenges, such as the difficulty ensuring that students watched the instructional videos prior to their lessons, were the most common obstacle to flipping K-12 science classes. This problem may also be associated with a common student-related challenge: the reluctance to participate in out-of-class activities since they may find the video-watching activity unchallenging and unmotivating (Lo & Hew, 2017, Zainuddin, 2018). Moreover, the faculty-related challenges identified in this review are in line with one of the two major barriers that K-12 teachers may encounter in FCs in Hong Kong: first-order barriers such as the accessibility of technology for students and the preparation time, training, and support required from teachers (Wang, 2017).

To overcome these challenges and implement FC in K-12 education effectively, Lo and Hew (2017) suggest 10 guidelines in their review, after which Lo (2018) refined the 10 recommendations based on Spector's (2016) six-pillars framework for the interdisciplinary perspectives of FCs. Further analysis based on the six pillars (see Table 2.9) determined that most of the K-12 science FC studies emphasized two pillars: the *Culture* pillar, which focuses on cultivating learner-centered instruction in the classroom culture, and the *Learning* pillar, which provides peer-assisted learning approaches during in-class meetings. The *Instruction* pillar was also grounded in the studies that incorporated an established model as the framework of their FC designs.

However, the *Interaction* pillar, which provides a discussion forum for students to interact and ask questions, and the *Learning* pillar, which provides students with optimally challenging learning tasks inside the classroom, were omitted by most of the studies on K-12 science education.

Table 2.9
Analysis of the scoped FC studies in K-12 science education based on Spector's six pillars

Study (author, year)	Spector's six pillars					
	Communication	Interaction	Environment	Culture	Instruction	Learning
Atwa et al. (2016)*	C1 C2	I3 I4		C7		L9 L10
Camiling (2017)*			E5	C7	I8	L10
Çetinkaya (2017)*		I4	E5	C7	I8	L10
Gariou-Papalexiou et al. (2017)	C1		E5	C7	I8	L10
Kettle (2013)				C7		L9 L10
Leo and Puzio (2016)		I4		C7		L10
Lo et al. (2018)#*	C2	I4	E6	C7	I8	L9 L10
Olakanmi (2017)	C1	I4		C7		L10
Schultz et al. (2014)*	C1 C2		E6	C7		L10
Sezer (2017)*		I4	E5	C7		L10
Slemmons et al. (2018)*	C1, C2	I4			I8	L10
Sookoo-Singh and Boisselle (2018)	C1		E5	C7	I8	
Stratton et al. (2020)	C1		E5	C7		L10
Yousefzadeh and Salimi (2015)#*				C7		L10
Zainuddin (2018)*		I4		C7	I8	L10

# = multi-disciplinary study with other subjects, * = significant results obtained
C1 = Introduce the FC approach to students and obtain parental consent, C2 = Use cognitive theory of multimedia learning to inform the production of instructional videos, I3 = Create a discussion forum for online interactions, I4 = Provide online quizzes on video lectures with computerized feedback, E5 = Provide human resources and technical resources to support FC practices, E6 = Adopt a school/faculty-wide approach to FC practices, C7 = Cultivate a classroom culture for learner-centered instruction, I8 = Utilize established models as the framework for FC design, L9 = Provide optimally challenging learning tasks with instructor's guidance, L10 = Use peer-assisted learning approaches during class meetings

Although online or synchronized out-of-class communication is not essential in FCs in K-12 education, Hwang, Lai, and Wang (2015) suggested that, "engaging students in seamless flipped learning implies that the students are encouraged to communicate with their peers and teachers across various learning spaces, including at-home, in-class, and in-field learning" (p. 458). Bhagat et al. (2016) also suggested that the creation of a discussion forum for online

Q&A sessions is necessary to promote student engagement. For the *Learning* pillar, optimal challenges in the in-class problem-based learning, together with teacher guidance, were also found to be effective at improving student achievement (Lo et al., 2018; Zainuddin, 2018), yet they are absent from the research on FCs in K-12 science education.

2.6.5 Implications for Future Research of Flipped Classroom in K-12 Science Education

This scoping review of the 15 identified studies provides an up-to-date overview of the design and implementation of FCs in K-12 science classes. Due to the variation in the results on the efficacy of FCs on student achievements, as well as the limitations found in the research designs of the studies, future FC research that focuses on K-12 science education is necessary. In line with some of the recommendations suggested by the existing FC reviews in other contexts, future research on K-12 science education should take the following approaches:

1. Ground the design of the FC in an established framework (Abeysekera & Dawson, 2015; Karabulut-Ilgu, Jaramillo Cherrez, & Jahren, 2018; Lo, 2018; O'Flaherty & Phillips, 2015).
2. Conduct a mixed-methods study that contains both quantitative and qualitative findings, such as interviews, lesson observations, and analyses of student work (Abeysekera & Dawson, 2015; Giannakos et al., 2014; Karabulut-Ilgu et al., 2018; Lo, 2017; Seery; 2015).
3. Employ a pre-test–post-test quasi-experimental design that consists of a modified FC treatment group, a traditional FC control group, and an additional control of a non-flipped TC for comparison (Lo, 2017; Lo & Hew, 2017).
4. Implement the FC intervention for a longer period (e.g., more than a half year) to avoid

any novelty effect (Karabulut-Ilgu et al., 2018; Lo & Hew, 2017).

5. Evaluate student learning outcomes that particularly improve student learning and development specifically for the objectives or needs of science education, such as basic science process skills (BSPS) and integrated science process skills (ISPS), as well as metacognitive skills, such as SRL abilities (Bernard, 2015; Karabulut-Ilgu et al., 2018; O'Flaherty & Phillips, 2015).

As flipped learning studies in other contexts have suggested that there is a discrepancy in terms of the impacts of FC on students with different learning abilities (e.g., Jong, 2017; Nouri, 2016), together with the limited studies suggested from this scoping review, the influence of FC among students with different learning abilities should be further explored to cater to the problem of learning diversity in K-12 science classrooms (Yeung et al., 2012; Yeung et al., 2013).

Various scoped studies have employed different strategies to overcome the major challenge of ensuring that students actively participate in the pre-class activities of the FC, such as using gamification to motivate students to compete in the out-of-class learning setting (Zainuddin, 2018). Incorporating a self-regulated monitoring system in flipped classrooms, whereby students are guided to set learning goals and perform self-evaluation in both out-of-class and in-class learning, is also a useful approach to engage students to participate in FCs (Lai & Hwang, 2016).

Therefore, this study employs a stimulating, effective, and established SRL strategy – POE (White & Gunstone, 1992) –into the FC to meet the subject needs. In traditional classrooms, POE has often been employed in the form of experiments in science laboratories to increase student motivation (Schraw et al., 2006) and clarify scientific misconceptions (Bahar, 2003;

Cinici & Demir, 2013). In flipped classrooms, a technology-enhanced environment with the use of mobile data loggers and the LMS PowerLesson2 is proposed to facilitate the POE activities outside the classroom (Yeung et al., 2019).

In the modified flipped classroom, students should first make predictions about certain scientific investigations, such as the temperature, light intensity, and gas changes in a jar of seedlings growing under different pH levels, so that they will experience goal-setting in the LMS. Then, students should self-monitor by making observations and measurements of their investigations via YouTube live-streaming and a mobile data logger. After that, they self-evaluate by explaining and reconciling differences between their observations and previous predictions, as well as clarifying their externalized misconceptions. The LMS also facilitates online communication between the teacher and students, satisfying the *Interaction* pillar in this FC. A brief review, mini lecture, and challenging inquiry-based learning activities that address the pre-class POE learning are then conducted in the face-to-face lessons.

However, there remains a lack of literature addressing the synergetic effect of incorporating the technology-enhanced POE activities and SRL approaches in a flipped learning environment. Hence, this research integrated and implemented such a science-specific strategy in a modified FC for students' SRL in secondary science education.

2.7 Learning Activities of the Modified Flipped Classroom

This section illustrates the beneficial effects from the use of TEL, POE and scientific inquiry strategies and discusses the implications for their incorporation in flipped learning.

2.7.1 Technology-Enhanced Learning in K-12 Science Education

According to Tsai (2017), TEL refers to

> the employment of technology in educational contexts, to assist the learning process and facilitate the communication between peers and teachers. Different from conventional face-to-face classroom lecturing, technology-enhanced learning not only facilitates the showcasing of multimedia teaching materials, but also encourages students to take initiative to research on their own, and to share with peers about their personal insights in online forums. (p 185)

To highlight the advantageous impacts of using technology in science teaching and learning, Linn (2003) explored the technology innovations in science education in five categories: (a) science texts and lectures, (b) science discussions and collaboration, (c) data collection and representation, (d) science visualization, and (e) science simulation and modeling.

Tamim, Bernard, Borokhovski, Abrami, and Schmid (2011), on the other hand, summarized the technologies into (a) word processor, (b) computer-assisted instruction, (c) computer-based instruction, (d) ICT, (e) simulations, (f) digital media and (g) hypermedia in their second-order meta-analyses of 25 reviews that covered 1,055 primary studies in science education. They concluded that the strength of TEL is to support students to learn in a proactive way, instead of acting as a tool to deliver content knowledge (Tamim et al., 2011). More recently, Tang and Tsai (2016) identified four major fields of TEL research in science education: (1) technology-enhanced science inquiry, such as comparisons of the improvement of student learning and understandings between conventional and technology-enhanced inquiry instructions; (2) simulation and visualization for understanding, such as studying the impacts of the activities that involve computerized simulations and animations in science learning; (3) technology-enhanced chemistry learning, such as researching the efficacy of a computerized laboratory on improving student chemistry understanding and graphing ability; and (4) game-based science learning, such as study to facilitate scientific habits that might include video online games and a three-dimensional (3D) game-based curriculum.

In Hong Kong, several studies have been conducted on the successful application of TEL in accordance with the aforementioned categories of technology or research directions. For instance, considering the use of TEL for simulation and visualization for understanding (Linn, 2003; Tamim et al., 2011; Tang & Tsai, 2016) in primary and secondary science education in Hong Kong, Yeung (2011) employed web-based applications of 3D visualization and virtual reality (VR) in secondary schools and teacher education. The findings revealed that Hong Kong teachers have high readiness and openness regarding incorporating 3D visualization and VR technology in their future teaching. Most secondary school students also had a positive attitude toward the learning of science using VR technology, and their learning effectiveness using the VR courseware was found to be high (Yeung, 2011).

Furthermore, studies have used technology-enhanced science inquiry (Tang & Tsai, 2016) and computer-assisted learning strategy (Tamim et al., 2011) to assist data collection and representation (Linn, 2003). For example, Tho, Chan, and Yeung (2015) designed and conducted community-based learning in secondary school physics at a theme park (Ocean Park) in Hong Kong. In this experiential learning, 208 students from nine secondary schools conducted computer-mediated experiments using the Wii remote controller system, its freeware *Wiimote physics* and the PASCO Roller Coaster System (Tho et al., 2015). The results of the paired sample *t*-test between pre- and post-test indicated that student academic performance was improved, with a large effect size, suggesting such student gains were not caused by excitement or interest in the ride itself.

Other, similar studies also incorporated such beneficial impacts of technology with positive effects on student science learning. These impacts include (1) the application of radio frequency identification (RFID) technology (Huang, Yeung, Kong & Gao, 2011) and (2) IP camera (Tho & Yeung, 2015) in scientific inquiries / investigations; (3) the use of Arduino-based datalogger in field-based learning, searching suitable sites for the generation of solar renewable energy and investigating the heat island effect in both a wetland park and residential areas (Yeung et al., 2015); and (4) the development of a remote laboratory system, which involves eight remote experiments, to allow secondary school students to perform real-time scientific investigation activities outside the science laboratory in schools (Tho & Yeung, 2018).

Considering the positive effects of these TEL on promoting student achievement and attitude toward the learning of science in K-12 science education in Hong Kong, this research adopts the innovative technology of the mobile data logger developed by Prof. Yeung Yau Yuen, the principal supervisor of this study, for affording the POE strategy in an out-of-class setting of the modified FC. The design of the modified FC was also published (Yeung, et al., 2019).

2.7.2 Self-Regulated Learning Strategies in K-12 Science Education

According to Schraw et al. (2006), self-regulated learners in science should able to (a) use cognitive strategy flexibly, which involves simple problem-solving and critical-thinking strategies; (b) have metacognitive control, which refers to the knowledge and control of cognitive skills needed for planning, goal-setting, implementing, monitoring, and self-evaluating the learning; and (c) have motivational beliefs, which refers to students' self-efficacies and epistemological world views regarding learning.

To promote students' SRL in science education, Schraw et al. (2006) recommended six general instructional strategies: (a) inquiry-based learning; (b) the role of collaborative support; (c) strategic instruction for problem-solving and critical-thinking; (d) the construction of a mental model for conceptual change; (e) the use of technology; and (f) the impact of student and teacher beliefs. In practice, Lai, Hwang, and Tu (2018) integrated a computer-supported SRL strategy into the science inquiry of an elementary class. Consequently, the students increased their tendency for SRL in terms of time management, help-seeking, and self-evaluation empirically (Lai et al., 2018).

Some features of this modified FC, comprising out-of-class technology-enhanced POE and in-class scientific inquiry strategies, as suggested in the previous sections, enable students to experience self-regulation in science learning. For example, the LMS of the FC, as well as the in-class collaborative and inquiry-based learning, provide students with social support from peers, which increases the student motivational process. Furthermore, the use of a mobile data logger and the application of POE activities prior to lessons also facilitate the cognitive process of data stimulation in the technology perspective, etc. Table 2.10, below, lists the ways the six instructional strategies increase student cognitive, metacognitive, and motivational processes in science SRL, as suggested by Schraw et al. (2006). The features of the FPOE that echo these instructional strategies are also pointed out.

Table 2.10

Ways the six instructional strategies increase cognitive, metacognitive, and motivational processes (Schraw et al., 2006)

	Cognitive processes	Metacognitive processes	Motivational processes
(a) Inquiry	Promotes critical-thinking through experimentation and reflection [SI]	Improves explicit planning, monitoring, and evaluation [SI]	Provides expert (e.g., teacher) modeling [SI]
(b) Collaboration	Models strategies for novices [TEL, SI]	Models self reflection [TEL, SI]	Provides social support from peers [TEL, SI]
(c) Strategies of problem-solving and critical-thinking	Provides a variety of strategies [POE, SI, TEL]	Helps students develop conditional knowledge [POE, SI, TEL]	Increases self-efficacy to learn [POE, SI, TEL]
(d) Mental model for conceptual change	Provides explicit model to analyse [POE, SI]	Promotes explicit reflection and evaluation of the proposed model [POE, SI]	Promotes radical restructuring and conceptual change [POE, SI]
(e) Technology	Illustrates skills with feedback. Provides models and simulates data [TEL]	Helps students test, evaluate, and revise models [TEL]	Provides informational resources and collaborative support [TEL]
(f) Impact of student and teacher beliefs	Increases engagement and persistence among students [POE, TEL, SI]	Promotes conceptual change and reflection [POE, TEL, SI]	Promotes modeling epistemology (the beliefs people have about the utility and credibility of models): characteristic of expert scientists [SI]

Possible benefits from the modified FC (FPOE): TEL = technology-enhanced learning including mobile data logger and LMS (out-of-class), POE = POE strategy (out-of-class), SI = scientific inquiry (in-class)

Note. Adapted from "Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning" by G. Schraw, K. J. Crippen, and K. Hartley, 2006, *Research in Science Education, 36,* p. 131.

The following sections discuss how out-of-class POE and in-class scientific inquiry facilitate students' SRL. Empirical findings on the incorporation of these strategies for promoting student learning at K-12 science education are also discussed.

2.7.2.1 Pre-class Predict-Observe-Explain Strategy

The POE strategy, an instructional approached developed by White and Gunstone (1992), is a useful constructivist strategy to engage students in student-centered scientific demonstrations (Treagust, 2007). According to White and Gunstone (1992), the POE strategy enables the educator to promote the understanding of students by allowing them to complete the following three tasks in sequence: (1) predict the results of certain events or scenarios consisting of scientific processes, so that students' current understanding of scientific phenomena can be probed; (2) observe and describe the scientific processes, so that the students' present knowledge and ideas that lead to cognitive conflicts, if their predictions and observations are contradictory, can be examined; and (3) explain and reconcile such conflicts, so that the students' misconceptions of science concepts can be externalized and modified. Palmer (1995) recognized that POE was a beneficial strategy for the identification of student understanding of their science knowledge and concepts, as well as the development of their SPS. Bahar (2003) advocated that POE was a powerful practice for the expression and modification of student biological misconceptions. Moreover, POE is regarded as a problem-solving strategy in terms of cognition (Schraw et al., 2006) and metacognition (Rickey & Stacy, 2000) in the learning of science. Kearney (2004) claimed that a computer-supported POE strategy could promote students to learn with peers in science. According to Schraw et al. (2006), the POE strategy, which was also regarded as a form of modeling active investigation strategies, could also help increase student motivation regarding learning science.

There are many studies on integrating POE strategies in secondary science education. For example, Güngör and Özkan (2016) integrated a POE approach into the teaching of enzymes in a biology class, finding that the students' science concepts could be improved by the notification of mistakes and the elimination of scientific misconceptions via the POE activities

(Güngör & Özkan, 2016). Cinici and Demir (2013) found that a cooperative approach of POE strategies effectively helped their students to understand better the concepts of diffusion and osmosis in a Grade 9 biology class. Wu and Tsai (2005) revealed that elementary students had better learning outcomes in a POE constructivist approach when learning biological reproduction in plant than with the conventional approach. However, only high achievers in the constructivist group had better inferring or explaining skills than those in the traditional counterpart. Smith, Edionwe, and Michel (2010) introduced POE activities into Grade 11 conductimetric titrations, and the students were positive regarding understanding the chemical concepts and principles. In physics, Chang et al. (2013) implemented a cyclical POE strategy, with successive POE activities integrated into the teaching of a Grade 9 topic of light. The results indicated that that this approach enhanced the reasoning skills of the physics students (Chang et al., 2013).

Some research has blended the POE strategy with other pedagogical approaches. For example, Kearney (2004) conducted a multimedia-supported POE in two senior science classes. The results revealed that this computer-based POE approach helped students to express their ideas during peer learning, especially when making predictions, observations, and reasoning during the POE activities (Kearney, 2004). The POE activities also promoted students to take control of their learning and provided students with more time to discuss and reflect during studying (Kearney, Treagust, Yeo, & Zadnik, 2001). Lati, Supasorn, and Promarak (2012) also employed science inquiry using a POE strategy to improve students' LA about the topic of chemical reaction by integrating SPS into a Grade 11 chemistry class.

2.7.2.2 In-Class Inquiry-Based Learning

Inquiry-based learning is a process in which student engagement, attained by posing questions and constructing a conceptual understanding, is the goal of the learning experience (Gunstone & Mitchell, 1998). This type of learning promotes self-regulation by (a) using cognitive strategies to stimulate students' active engagement in the learning process; (b) using metacognitive strategies to monitor students' understanding; and (c) increasing motivation by using active-learning strategies such as constructing graphs and tables (Schraw et al., 2006). Several studies have also suggested that inquiry-based learning could enhance student learning performance (e.g., Maxwell, Lambeth, & Cox, 2015; Şimşek, & Kabapınar, 2010).

Blanchard et al. (2010) summarized the instructional approaches used in inquiry-based learning into four levels focusing on three key activities: asking questions, collecting data, and interpreting those data (Abrams, Southerland, & Evans, 2007), as displayed in Table 2.11.

Table 2.11
Levels of inquiry-based learning (Blanchard et al., 2010)

	Source of questions	Data collection methods	Interpretation of results
Level 0: Verification	Given by teacher	Given by teacher	Given by teacher
Level 1: Structured	Given by teacher	Given by teacher	Open to student
Level 2: Guided	Given by teacher	Open to student	Open to student
Level 3: Open	Open to student	Open to student	Open to student

Note. Reprinted from "Is inquiry possible in light of accountability?: A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction" by M. Blanchard, et al., 2010, *Science Education, 94*(4), p. 581.

Scientific inquiry, a pedagogy usually applied in inquiry-based learning, is often involved in secondary science education (Anderson, 2002; Bass, Contant & Carin, 2009). According to Bass et al. (2009), students can develop a conceptual understanding of science during the process of science inquiry. Instead of asking students to find the 'correct answer,' the engagement in science as inquiry could be far more vital (Bass et al., 2009). It has also been suggested that students who participate in scientific inquiry could learn facts, concepts, principles, models, theories, and explanations about science (National Research Council, 1996).

In scientific inquiry, students should be able to carry out the following tasks (see Figure 2.9): (a) asking questions about objects, organisms, and environment; (b) planning and conducting a simple investigation; (c) using appropriate tools and techniques to gather and interpret data; (d) using evidence and scientific knowledge to develop explanations; and (e) communicating investigation procedures, data, and explanations to others (National Research Council, 1996). Bennett (2003) claimed that scientific inquiry, which engages students to act as scientists, should be distinguished from other activities that engage students to arrive at pre-determined answers to scientific problems.

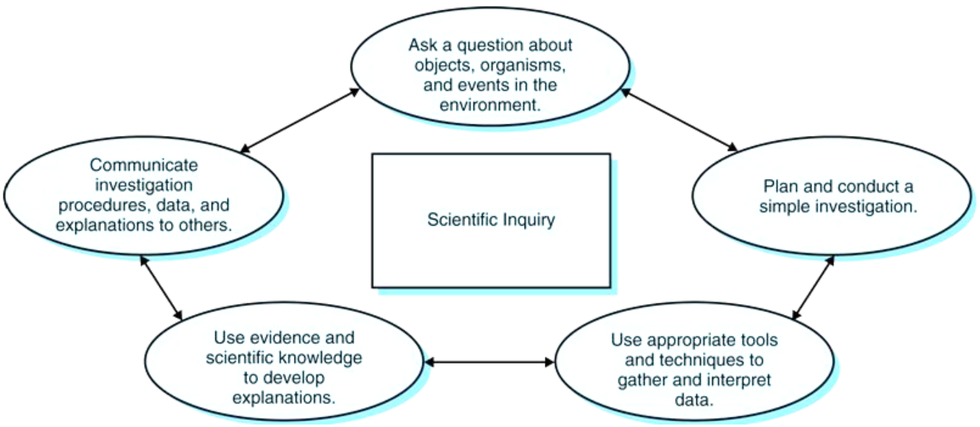

Figure 2.9. Tasks of scientific inquiry

Reprinted from *Teaching science as inquiry* (11th ed.) (p. 20), by J. Bass, T. Contant, and A. Carin, 2009. Boston, Mass.; Hong Kong: Allyn & Bacon.

However, Donovan and Bransford (2005) stressed that assessing students' preconceptions and evaluating students' participation with metacognitive strategies, as well as allowing student participation in the learning processes are essential in scientific inqury (Donovan & Bransford, 2005). This thinking is in line with Bass et al.'s (2009) viewpoint that the weights of the tasks in scientific inquiry can be adjusted because of the flexiblity of the methods and approaches when conducting scientific research from a scientist's perspective.

Nevertheless, scientific inquiry might involve the deployment of different process skills. In particular, Bass et al. (2009) suggested that (a) observing, (b) classifying, (c) interfering, (d) measuring, (e) communicating, (f) predicting, (g) hypothesizing, and (h) experimenting are the meaningful science processes that could be used as intellectual skills during a complete process of scientific inquiry.

Moreover, the SPS are categorized into BSPS and ISPS (Rezba, Sprague & Fiel, 2003). The first category, BSPS, consists of the skills of observing, inferring, measuring, communicating, classifying, and predicting (Padilla, Cronin, & Twiest, 1985; Ostlund, 1992; Rezba et al., 2003), whereas ISPS comprises the skills of identifying variables, constructing hypotheses, operationally defining, designing investigations, experimenting, formulating models, and interpreting data (Bailer, Ramig & Ramsey, 1995; Burns, Okey, & Wise, 1985, Ostlund, 1992; Rezba et al., 2003).

In Hong Kong, the most up-to-data science (S1–S3) curriculum also regards SPS as one of the important components for students' SL. According to the CDC (2016), those SPS include (a) observing, (b) classifying, (c) designing investigations, (d) conducting practicals, (e) inferring, and (f) communicating (CDC, 2016).

Several studies focusing on inquiry-based learning have been conducted in primary and secondary science education in Hong Kong. For example, Yip (2005) evaluated the inquiry-based activities suggested by the laboratory manuals on the topics of states of matter, burning, and electrical resistance at Grade 7 and 8 junior science. The findings suggested that most of the activities in the laboratory manuals were too prescriptive, only asking students to look for the correct results of the experiments without any active and independent involvement in learning (Yip, 2005).

In addition, Cheng and Tsoi (2005) employed several inquiry-based learning activities on the topics of force, and acid and alkali in Grade 8 science in Hong Kong. According to the findings, the inquiry-based learning activities that integrated daily-life examples were very important for enhancing student participation (Cheng & Tsoi, 2005). Moreover, inquiry using open-ended design tasks could help students to master the investigations (Cheng & Tsoi, 2005).

Cheung (2016) investigated students' self-efficacy in scientific inquiry, including planning a fair test, collecting experimental data, analyzing and reporting data, drawing conclusions, and identifying sources of experimental errors in a Grade 2 top-band secondary school in Hong Kong. The findings revealed that the students' efficacy regarding the handling of apparatus and chemicals safely, which were procedural issues for conducting the inquiry, was the highest, while the efficacy of using appropriate tables and graphs to present and analyse data and draw conclusions was the lowest (Cheung, 2016).

For the implementation of scientific inquiries at senior secondary level in Hong Kong, Ng and Yeung (2000) pioneeringly integrated computer-assisted dataloggers in three advanced-level physics investigations. Despite the benefits for learning as reported by the students, their performance in the investigation was unimproved as such innovative approach of inquiry was uncommon at that time (Ng & Yeung, 2000).

On the other hand, Cheung (2011) also discovered several obstacles regarding implementing scientific inquires in the chemistry laboratory. The obstacles were: (a) limitation of time in the class, (b) lack of effective instructional resources, and (c) problems of managing a class with large class size during scientific inquiry. These obstacles meant the researcher recommended that laboratory inquiries should be designed as guided rather than open. Such a recommendation contradicts Cheng and Tsoi's (2005) findings regarding using scientific inquiry with an open-ended approach at junior secondary level in Hong Kong.

2.7.3 Implications of the Learning Strategies in this Research

By integrating technology-enhanced mobile data loggers, the POE strategy is incorporated in the out-of-class learning environment, while scientific inquiry, which is a form of inquiry-based learning, is also integrated in the in-class face-to-face setting of the FPOE. There are several positive impacts that benefit students in science learning with the help of TEL, POE, and inquiry-based learning outside the FC context. However, it is not known whether, nor to what extent, these leaning strategies are suitable for the FC approach. Moreover, several challenges regarding the integration of inquiry-based learning in Hong Kong, especially the lack of time might be overcome using FC. Nevertheless, the effect of incorporating inquiry-based learning into a flipped learning environment is also unknown in real practice. Therefore, it is essential to investigate the efficacy of the FPOE in secondary science education in Hong Kong.

2.8 Assessments of the Impacts of the Modified Flipped Classroom in this Study

As discussed in previous sections, there is a lack of studies on the subject-specific impacts of FC in secondary science education, students' SL in terms of LA and SPS, which is the emphasis of secondary-level science education in Hong Kong, and SRL abilities, which are suggested as being necessary to improve SL (CDC, 2017a). All these aspects are assessed in this research.

Scientific literacy is a complex concept that has been debated for more than two decades (Fan & Geelan, 2013; Yore, Pimm & Tuan, 2007). According to Vieira and Tenreiro-Vieira (2016), "science researchers and educators as well as various organizations have developed rationales and highlighted characteristics, mainly in terms of knowledge and skills, expected of a scientifically literate person" (p. 664).

As mentioned in the previous introductory chapter, the PISA framework advises that SL consists of (a) content knowledge, such as of the facts, concepts, ideas, and theories about the natural world that science has established, which supports one when explaining phenomena scientifically; (b) procedural knowledge, such as repeating measurements to minimize errors and to reduce uncertainty and to control variables; and (c) epistemic knowledge, such as an understanding of the function that questions, observations, theories, hypotheses, models, and arguments play in science, which helps one to design scientific inquiry and interpret data (OECD, 2019a). National Research Council (1996) also defines SL as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (p. 22).

In Hong Kong, the CDC (2017a) specifically pointed out that that students' SL refers to their ability to apply (a) scientific knowledge and (b) SPS to tackle issues and problems related to their daily life and the natural world (CDC, 2017a). Fan and Geelan (2013) also regarded SPS as one of the four dimensions of science learning that considers students' SL. Thus, this research investigates the improvement of students' LA, focusing on content knowledge of science, and their SPS, which emphasizes procedural and epistemic knowledge. Taken together with the need to study SRL in FCs, this research evaluates how students improve their SRL, LA, and SPS in the FPOE and TFC in junior secondary science education in Hong Kong.

2.9 Conceptual Framework of this Research

Using the literature review, the discussion regarding the implications and the identification of the research gaps regarding flipping science classrooms in K-12 education, conceptual framework for this study is constructed. Figure 2.10 illustrates the conceptual framework, in which the two independent variables – (1) the type of flipped pedagogies with or without integrating technology-enhanced POE (i.e., TFC and FPOE) and (2) student learning abilities (i.e., lower and higher) – have been issued for investigation. The effects of the FC on students' SRL, LA, and SPS are evaluated. Data from a historical control group of TC were collected for analysis to compare with the flipped pedagogies. More details about the research design are described in the next chapter.

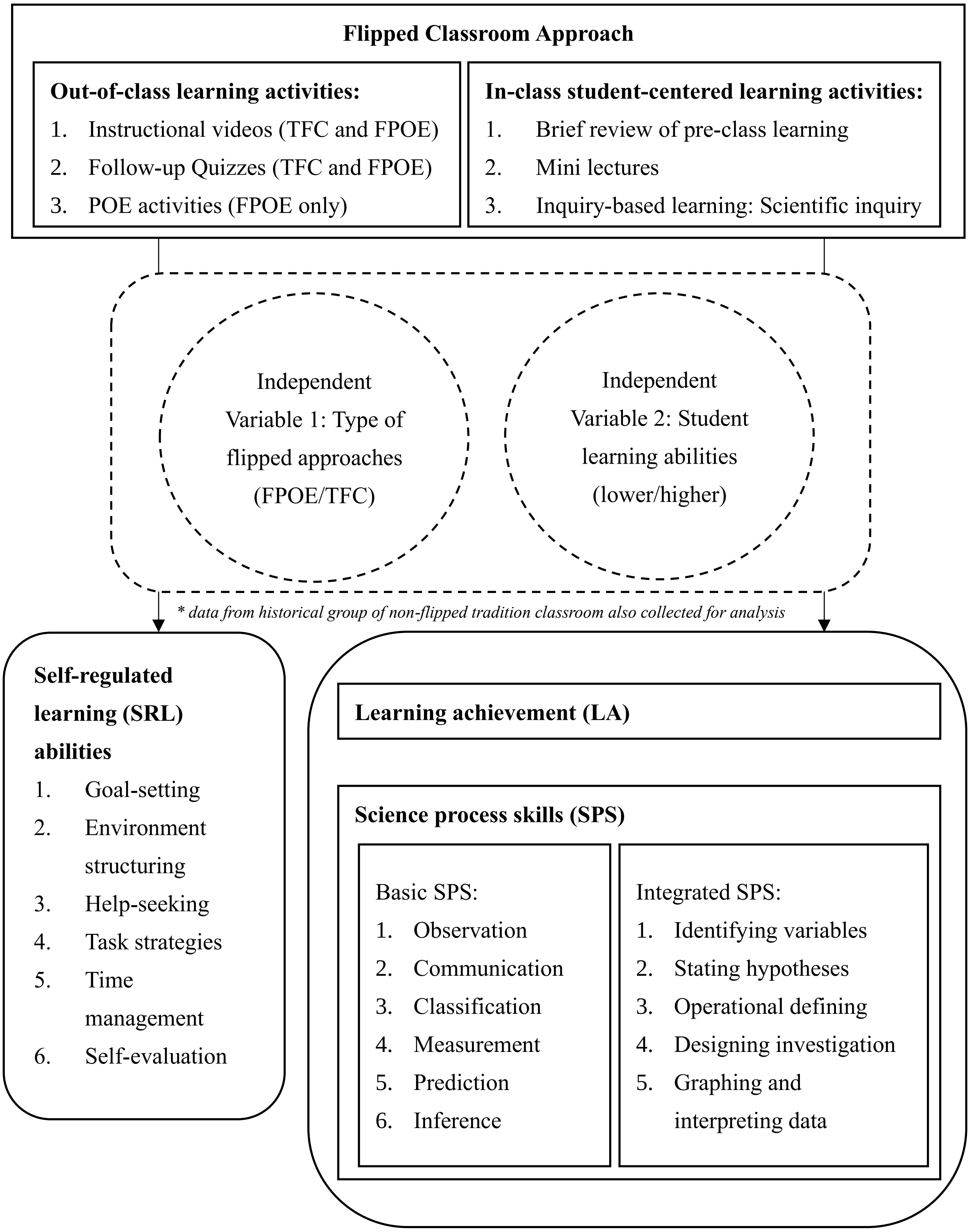

Figure 2.10. Conceptual framework of this research

Chapter 3: Methodology

3.1 Introduction

This chapter begins with the research context, including the backgrounds of the participants, the targeting of the population, the designs of the flipped and traditional classrooms, and a description of how they were incorporated in the school curriculum (Section 3.2). Second, this chapter describes and explains the research method and design to address the RQs (Section 3.3). Then, this chapter describes the features of the instruments and explains why they are suitable for this study (Section 3.4). The threats of the validity and reliability of the research are then discussed (Section 3.5). This chapter also outlines the procedures of data collection, including the ethical approvals and the schedules of administering (Section 3.6). Next, this chapter provides an in-depth description of the methods for data analysis (Section 3.7). Ethical issues and limitations of the research are then discussed (Section 3.8). Finally, a summary of the chapter is provided (Section 3.9).

3.2 Research Context

3.2.1 Background of Participants

In total, 187 Form 2 (Grade 8) students, aged 13–14, from a Hong Kong secondary school, participated in this study. The school is a government-aided secondary school founded in 1949 under the supervision of Tsung Tsin Mission of Hong Kong, which is one of the eight Lutheran bodies in Hong Kong. The school comprises approximately 20% top-band and 80 % middle-band students in the three-bandings categories of secondary schools in Hong Kong. Among the 187 students who participated in this study, 95 were male and 92 were female.

For the FC interventions, the total sample size of the FPOE and TFC groups was 124. Both FCs were implemented for a seven-month period throughout the two school terms in the academic year 2018–2019, which was long enough to prevent a short-term boost of student performance due to the novelty effect. Historical data from 63 students in a TC from the previous academic year (2017–2018) were obtained as additional control data for further analysis.

All the participating students were inexperienced with the learning process in any robust design of FCs. The students were only familiar with the in-class inquiry-based learning activities from when they were in Form 1 (Grade 7). They had also been using the information-retrieving and communicating functions of the school-based LMS, PowerLesson2, for different subjects. Several workshops introducing LMS were provided in the computer studies classes in Form 1 (Grade 7) in the previous academic year.

In each pedagogical group, the students were assigned by the school into two different but intact classes of higher or lower learning abilities based on their previous academic achievement, which comprised student performance in all subjects in the final examination of the previous academic year. For further confirmation, independent sample *t*-tests on the average scores of the students' previous academic performances were conducted to ensure that there were significant differences in the student learning abilities among the higher and lower-achieving classes within each pedagogical group. Five students from the current cohort and four students from the historical cohort were repeaters; hence, their previous academic performance scores were absent from the *t*-tests.

For the experimental group of FPOE, the independent sample *t*-test results found there was a significant difference of learning ability between the students in higher-achieving class (2A) and that in lower-achieving class (2C) from 2018–2019, with $t(58) = 8.30$, $p < .001$ (two-tailed).

On average, students in higher-ability class (*M* = 59.84, *SD* = 4.85) had higher academic performance scores from the previous year than those in lower-ability class (*M* = 50.58, *SD* = 3.59).

For the control group of TFC, an independent sample *t*-test result found there was a significant difference of learning ability between the students in higher-achieving class (2B) and those in lower-achieving class (2D) from 2018–2019, with $t(57) = 8.48$, $p < .001$ (two-tailed). On average, students in higher-ability class (*M* = 60.82, *SD* = 4.85) had higher performance scores from the previous year than those in lower-ability class (*M* = 50.71, *SD* = 4.24).

For the historical control groups of TC (2017–2018), the independent sample *t*-test results found a significant difference of learning ability between the higher-achieving class (2B) and the lower-achieving class (2C), with $t(57) = 8.28$, $p < .001$ (two-tailed). On average, students in the higher-ability class (*M* = 60.85, *SD* = 5.910) had higher performance scores from the previous year than those in the lower-ability class (*M* = 49.33, *SD* = 4.535) (one-tailed). Table 3.1 summarizes the arrangement of intervention groups and the *t*-tests results.

Table 3.1
Arrangement of intervention groups and the results of independent sample t-tests between different classes of different learning abilities (higher / lower)

Group	Pedagogy	Class	Learning ability	Teacher in charge	*N* (male: female)	Year	*Sig. (two-tailed)*
Experimental (*n* =63)	FPOE	2A 2C	Higher Lower	Researcher Teacher A	32 (15:17) 31 (14: 17)	2018–2019	.00
Control (*n* =61)	TFC	2B 2D	Higher Lower	Teacher B Researcher	31 (18:13) 30 (16:14)	2018–2019	.00
Additional (Historical) control (*n* =63)	TC	2B 2C	Higher Lower	Researcher Teacher A	32 (14:18) 31 (18:13)	2017–2018	.00

Furthermore, ANOVAs were conducted to confirm that (a) students from higher achieving classes (FPOE: 2A, TFC: 2B and TC:2B) performed similarly, with $F(2,92) = .385$, $p =.682$; and (b) students from lower achievement classes (FPOE: 2C, TFC:2D, TC: 2C) performed similarly, with $F(2,80) = .938$, $p =.396$.

3.2.2 Rationales for Targeting the Population

There are several reasons for targeting the population in this study. First, familiarity with the background of the Form 2 (Grade 8) students and their learning styles and performance from the researcher, who was also the science subject teacher of most of the targeted Form 2 students in the current and previous years, helped to design and implement the flipped learning approaches into the science lessons to meet the students' needs. As suggested by Lang and Page (2011), the understanding of students in the design of a practice may help to ensure that it fits within the classroom routine because logistical limitations of the classroom can be determined by the teacher. In this case, the role of the researcher as the subject teacher of the participating students was beneficial for the accurate implementation of the intervention in the classroom (Lang & Page, 2011).

Second, the researcher had been the chairperson of the science panel of the school for seven years, since 2013, and possessed rich experience in designing and implementing a school-based curriculum with the collaboration of other subject teachers, enabling the incorporation of the learning activities into all Form 2 classes in a more collaborative and effective manner. Thus, the researcher was able to plan the objectives for science education in the junior forms in the school holistically and to evaluate the school-based science learning activities in Form 2 critically. This knowledge helped the researcher to become a reflective practitioner (Stenhouse, 1975) who was eager to question and study the effectiveness of his own teaching practices, as well as enthusiastic to collaborate with colleagues to enhance his professionalism (Wright, 2015). These experiences undoubtedly provide insights helpful for choosing a suitable level of junior science curriculum for the intervention in this study. Hence, students from Form 2 were selected as they have acquired adequate knowledge and experience of scientific investigations (CDC, 2017b) essential for participating in out-of-class POE activities and in-class scientific inquiries in this study.

Third, the researcher's role as science panel chairperson aided the obtaining of consent and co-operation from the school, colleagues, and students in the school to be studied. The researcher had access to the historical records of the participants' previous academic achievements with the permission from the school principal, allowing greater flexibility in the design of the study based on historical data for analysis. Hammersley (1993) mentioned such advantages: "the teacher already has relationships with others in the setting and can use these in order to collect further data. Once again, an outsider would need to spend a considerable time in the field building up such relationships" (p. 432).

3.2.3 The Design of the Modified Flipped Classroom (FPOE)

Premised on the design of the FC (Bergmann & Sams, 2012; Bishop & Verleger, 2013; Lo & Hew, 2017), this research proposes a modified FC using an out-of-class technology-enhanced POE strategy (FPOE), in which POE activities are integrated into a school-based LMS, PowerLesson2, with videos or real-time experiments prior to the in-class inquiry-based learning.

3.2.3.1 Out-of-class Learning Activities

In each POE activity, the students completed three stages: (Stage 1: Predict) First, the students needed to predict the results of certain scientific scenarios by watching a video or real-time experiment broadcast through YouTube livestreaming, so that their present understanding of the scientific phenomena could be probed; (Stage 2: Observe) Then, the students were required to make online observations according to their present knowledge and ideas in the LMS, in which any cognitive conflict between their predictions and observations might be occurred. Furthermore, the students could browse the data collected from the innovative mobile logger (Yeung et al., 2019) in an online sharing drive (Google Drive) and make use of the automatic graph-plotting function of the logger application during the observation stage; (Stage 3: Explain) Finally, the students explained the experimental results in the LMS, in which the conflicts between their predictions and observations were reconciled, and any misconceptions of the science concepts they had were clarified (White & Gunstone, 1992).

The technology-enhanced POE activities incorporated in the LMS used either (a) experimental videos or (b) real-time online experiments with the integration of the innovative mobile loggers (Yeung et al. 2019). Figures 3.1 and 3.2 display the features of the two forms of out-of-class technology-enhanced POE strategy of this modified FC.

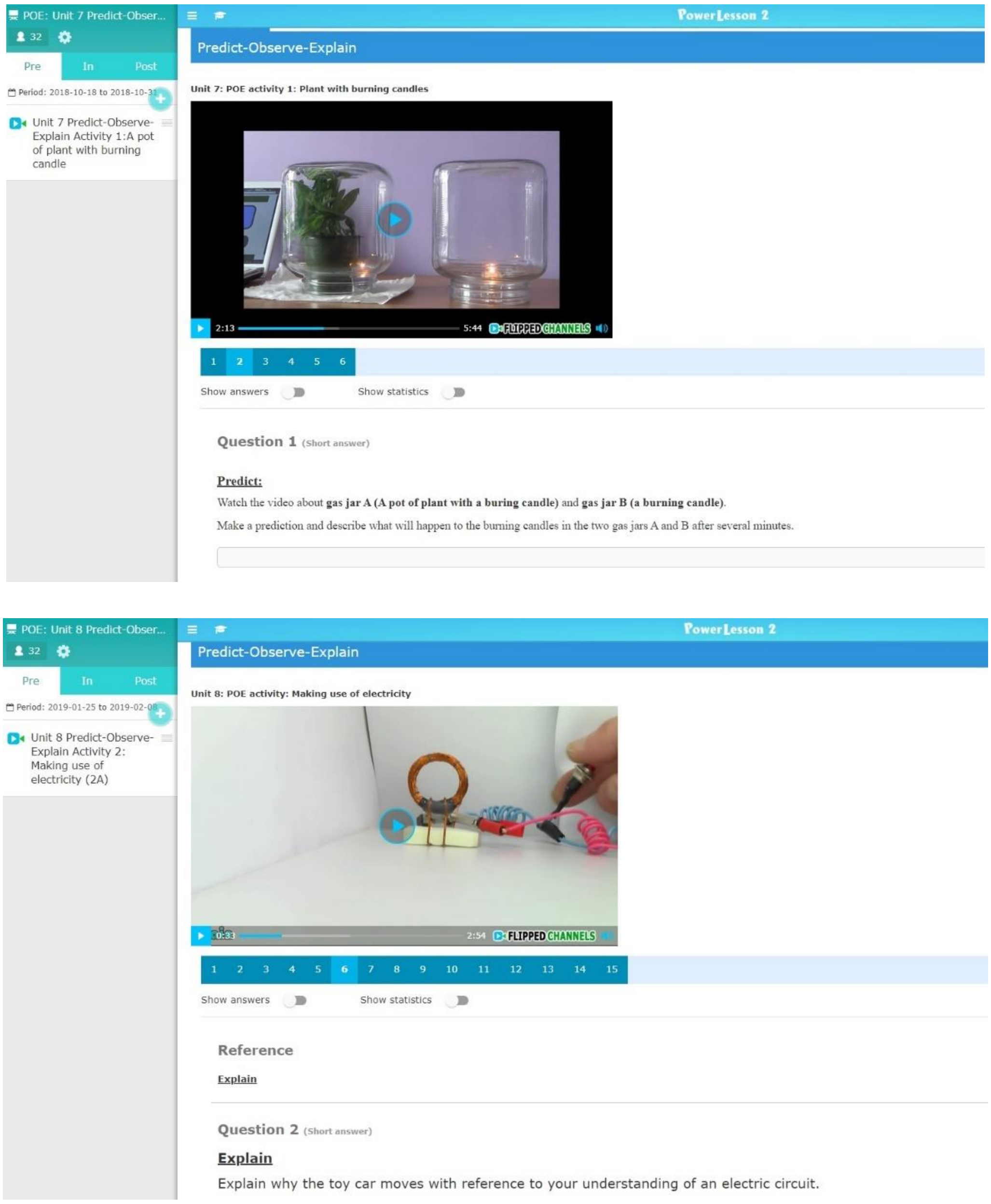

Figure 3.1. *Technology-enhanced POE strategy with the use of videos in the modified FC*

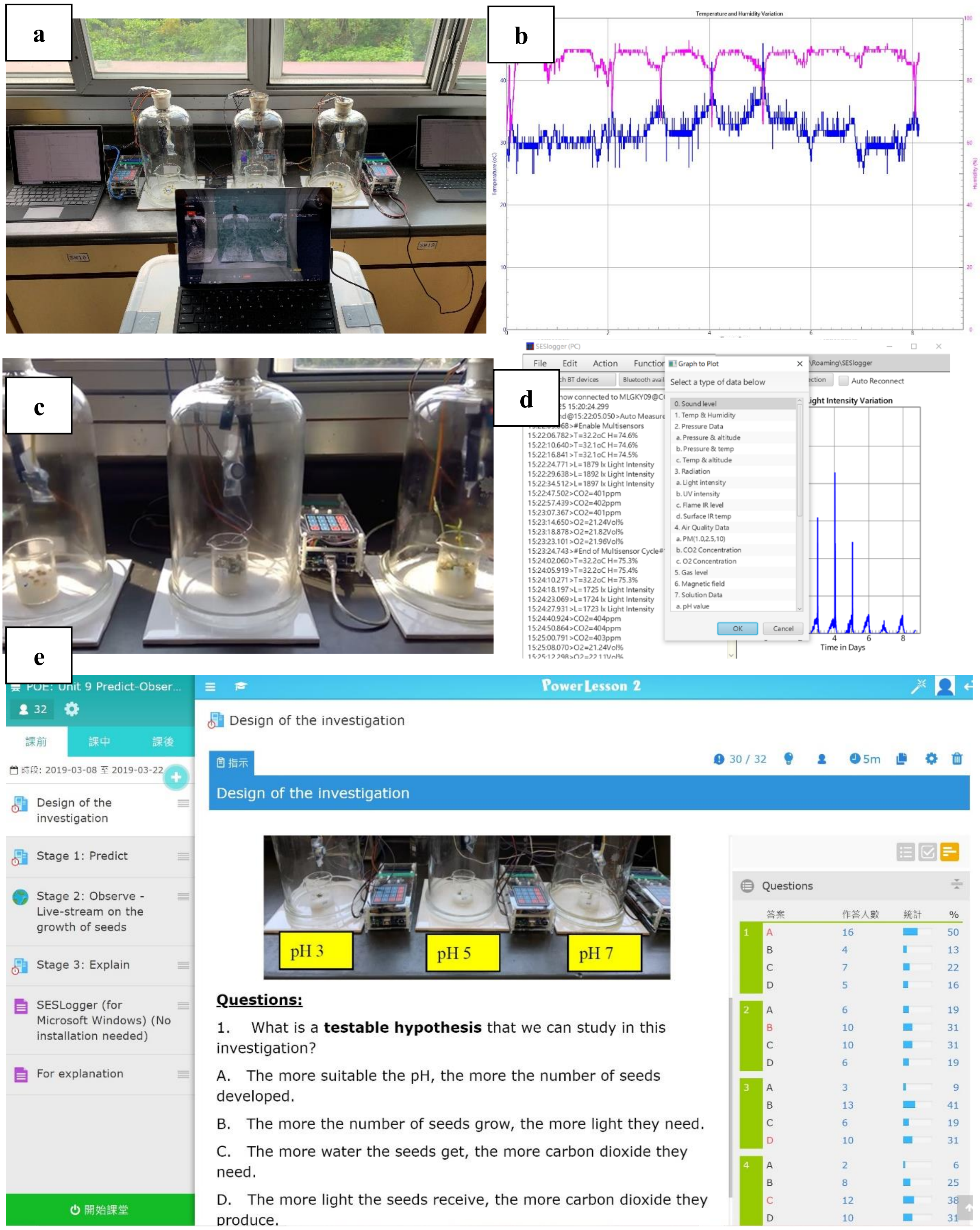

Figure 3.2. Technology-enhanced POE strategy with the use of mobile data loggers and LMS in the modified FC: (a) setup of the mobile data logger for POE in a science laboratory; (b) screenshot of the automatic graph-plotting function for the measurement of temperature and

relative humidity with the help of the logger application; (c) image of the growth of seedlings during student observations using YouTube live-streaming; (d) mobile logger application for self-experimentation; (e) pre-class online POE activity enabled by the LMS.

The SRL theory is rooted in the POE strategy as a theoretical framework in the FPOE. The students who participated in the technology-enhanced POE activities with the use of mobile loggers in the LMS might have experienced the three cyclical phases of self-regulatory processes suggested by Zimmerman (2002). For example, the students needed to set their goals for the scientific investigations in the first stage of the POE, in which they could choose which factors, such as temperature, light intensity, or gas contents in a jar of seedlings growing to be studied through the LMS. The students also needed to self-monitor the progress of mobile experiments by making observations using YouTube live-streaming, and conducting measurements by downloading the log files uploaded to the Google Drive together with use of the mobile logger application in the second stage of the POE. Then, they self-evaluated their findings by explaining and reconciling differences between their observations and previous predictions, as well as clarifying their externalized misconceptions in the LMS in the third stage of the POE. The LMS also facilitates online communication between the teacher and students in this out-of-class stage of learning. Figure 3.3 illustrates the design of out-of-class POE activities embedded within the SRL theoretical framework.

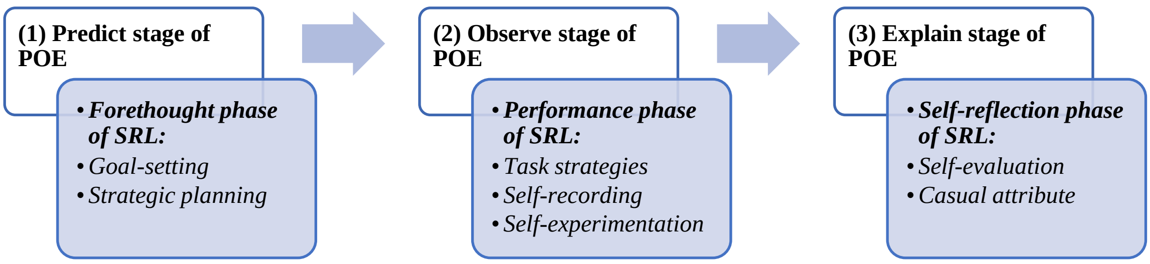

Figure 3.3. The design of out-of-class POE activities embedded within SRL theory

In the FPOE, instructional videos were introduced to each sub-unit. To help students to engage and focus on the terms of CLT (Slemmons et al., 2018), the length of the videos was limited to five minutes. Subsequent quizzes, comprising multiple-choice and short, structured questions, were used, and feedback regarding the answers was immediately provided in the LMS for students' evaluation following completion. Figure 3.4 shows is an example of the instructional video and quizzes in the modified FC.

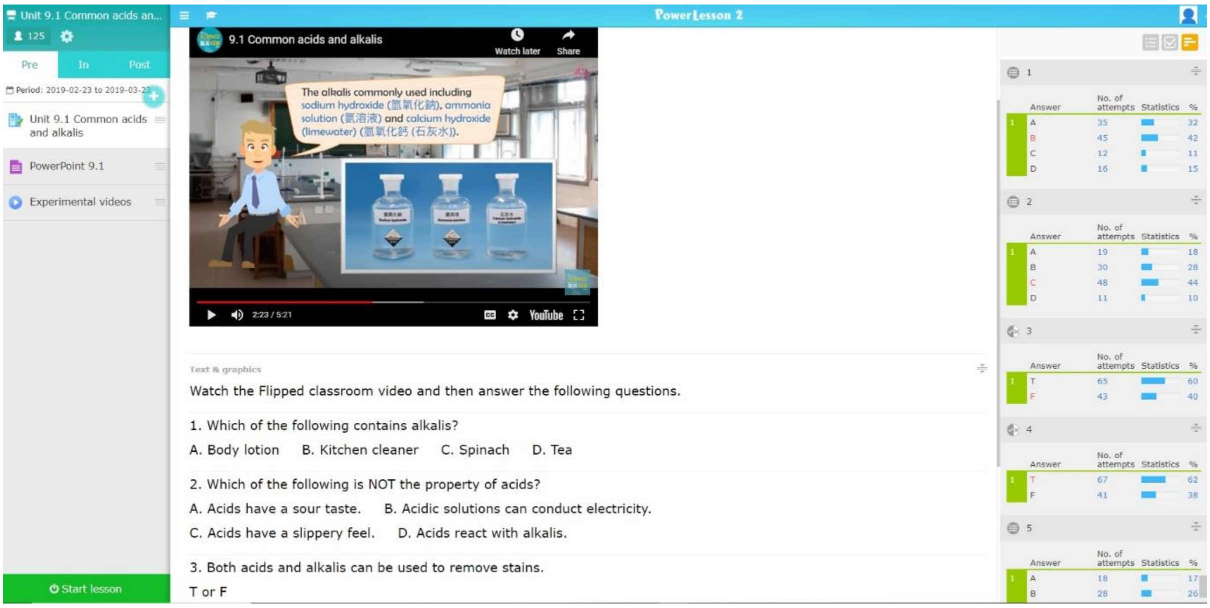

Figure 3.4. An example of the instructional video and quizzes in the FC

3.3.3.2 In-Class Learning Activities

After finishing the technology-enhanced POE activities, the students engaged in face-to-face lessons that comprised (a) a short briefing about the pre-class learning (Lo & Hew, 2017), (b) a mini lecture (Lo et al. 2018), and (c) student-centered learning activities (Bishop & Verleger, 2013). For the student-centered learning, guided inquiry-based learning (Blanchard et al., 2010) of scientific inquiries that related to the out-of-class learning was provided for the students to elaborate collaboratively and to achieve a higher-order level of learning, as mentioned in

Bloom's revised taxonomy as the intended learning outcomes (Sams & Bergmann, 2013; Wang, 2017; Wong & Cheung, 2015). Appendix 2 contains an example of the lesson worksheets of the scientific inquiry for the investigation of acidity solutions using neutralization in Unit 9: Acid and Alkali.

3.2.4 The Design of the Traditional Flipped Classroom (TFC)

In contrast to the FPOE, a TFC approach was set as a control, in which direct instructional videos and follow-up quizzes were prepared for students to watch prior to lessons, and the face-to-face class time gained was then used to carry out (a) a short briefing about the pre-class activities, (b) a mini lecture, and (c) collaborative scientific inquiries similar to that in the FPOE.

Both the FPOE and the TFC were implemented according to a modified 5-E instructional model (Lo, 2017) as the pedagogical framework, in which *Engage*, *Explore*, *Explain* and *Evaluate* phases were incorporated in the out-of-class learning, and *Engage*, *Explore* and *Evaluate* phases were employed in the in-class scientific inquiries.

3.2.5 The Design of the Non-flipped Traditional Classroom (TC)

Adopting the method suggested by Jensen et al. (2015), an additional historical control of a TC from the previous academic year (2017–2018) was used to compare the students' learning with the FC interventions. These TCs consisted of students (n = *63*) with backgrounds, such as learning ability and gender proportion, similar to the students in the FC interventions of the current cohort, 2018–2019. Except for the incorporation of out-of-class activities, equivalent methods of instructional delivery and inquiry-based scientific inquiries were carried out in the TC lessons of the historical cohort. Pedagogically, a conventional 5-E instructional approach (Bybee et al., 2006) was adopted by the subject teachers in the TC lessons. Figure 3.5 shows an overview of the pedagogical designs of the TFC, FPOE, and TC.

Current cohort			**Historical cohort**	
Modified 5E pedagogical framework (Lo, 2017)	**TFC (2018–2019)** Activities	**FPOE (2018–2019)** Activities	5E pedagogical framework (Bybee et al., 2006)	**TC (2017–2018)** Activities
Out-of-class setting				
Engage → *Explore* → *Explain* → *Evaluate*	1. Watch videos of direct instruction of science knowledge 2. Quizzes on videos with instant feedback	1. Carry out POE activities with videos or real-time experiments using mobile loggers 2. Clarify misconceptions 3. Watch videos of direct instruction of science knowledge 4. Quizzes on videos with instant feedback		
In-class setting				
Engage → *Elaborate* → *Evaluate*	1. Short briefing about pre-class activities 2. Mini lecture 3. Collaborative scientific inquires	1. Short briefing about pre-class activities 2. Mini lecture 3. Collaborative scientific inquires	*Engage* → *Explore* → *Explain* → *Elaborate* → *Evaluate*	1. Lecture 2. Collaborative scientific inquiries
After-class setting				
Homework assessment related to the in-class scientific inquiries				

Figure 3.5. Pedagogical designs of the TFC, FPOE, and TC

3.2.6 Incorporation of the Flipped Classrooms into the School Curriculum

The FCs were incorporated into the school science curriculum for seven months, from October

2018 to April 2019. The FCs covered three units from the junior science curriculum in Hong Kong (CDC, 2017b): Unit 7: Living Things and Air, Unit 8: Making Use of Electricity, and Unit 9: Common Acids and Alkalis. The suggested lesson time allocation for the three units is 26 hours for Unit 7, 27 hours for Unit 8, and 17 hours for Unit 9 (CDC, 2017b).

In the FPOE, each unit of the school curriculum consisted of two technology-enhanced POE activities. Due to the nature of scientific knowledge, one POE activity using video and one POE activity using a real-time experiment were developed for Unit 7: Air, which is related to biology knowledge, and Unit 9: Acid and Alkali, which is related to biology and chemistry knowledge. Two POE activities using videos were developed and included in Unit 8: Electricity, which is mainly related to physics.

For both the FPOE and the TFC, an instructional video and subsequent quiz were provided for each sub-unit, as well as three explorative and collaborative scientific inquiries provided for each unit. In total, 15 hours, which is about 21% of the total in-class teaching time, were allocated to the nine scientific inquires during the lessons. Table 3.2 summarizes the quantity of teaching materials and activities of the school curriculum that incorporated the FCs.

In total, 24 instructional videos, 24 quizzes, and nine scientific inquiries were conducted in the school curriculum incorporating the FPOE and TFC, while six POE activities were provided for the FPOE in the current year. For the TC in the previous academic year, the same scientific inquiries were conducted in the lessons without flipping the classes.

Table 3.2

Summary of the teaching materials and activities of the school curriculum incorporated with the FCs

Sub-unit	Topic	Out-of-class learning: POE video*	POE real-time*	Instruct-ional video	Quiz	In-class learning: Scientific inquiry
7.1	Air			✓	✓	
7.2 A	Photosynthesis			✓	✓	
7.2 B-C	Tests / factors of photosynthesis			✓	✓	✓
7.2 D	Significance of photosynthesis			✓	✓	
7.3	Respiration			✓	✓	
7.4 A	Gas exchange in plants	✓#		✓	✓	✓
7.4 B-1	Gas exchange in animals	✓#	✓	✓	✓	✓
7.4 B-2	Effects of smoking in humans			✓	✓	
7.5	Balance of carbon dioxide and oxygen in nature			✓	✓	
7.6	Air quality			✓	✓	
8.1	Introducing simple circuits			✓	✓	
8.2	Circuit diagrams			✓	✓	
8.3A-B	Basic ideas of an electric current			✓	✓	
8.3 C	Heating and magnetic effects	✓		✓	✓	✓
8.4	Voltage			✓	✓	
8.5	Resistance			✓	✓	✓
8.6	Series and parallel circuits	✓		✓	✓	✓
8.7	Our household electricity			✓	✓	
8.8	Electricity safety			✓	✓	
9.1	Common acids and alkalis			✓	✓	
9.2	Acid-alkali indicators and pH			✓	✓	✓
9.3	Neutralization			✓	✓	✓
9.4	Corrosive nature of acids		✓	✓	✓	
9.5	Potential hazards to their use	✓		✓	✓	✓

= activities for crossing subunits, * = only available for FPOE

Prior to the implementation of both the FPOE and the TFC, a briefing session on the purpose of the study and a workshop on the use of LMS for enabling the FC were conducted in science lessons between 9 October 2018 and 10 October 2018 for the four classes. Consent forms, including student and parental consent, were provided and received from the participants prior to the FC interventions. Table 3.3 outlines the timeline of the implementation of the FCs into the school curriculum in this study.

Table 3.3
Timeline of the implementation of the FCs into the school curriculum in this study

Timeline	Oct 2018#	Nov 2018	Dec 2018	Jan 2019	Feb 2019	March 2019	April 2019
Unit	7	7	7 and 8	8	8 and 9	9	9
Topic	Air	Air	Air / Electricity	Electricity	Electricity / Acid and alkali	Acid and alkali	Acid and alkali
Instructional videos and quizzes	✓	✓	✓	✓	✓	✓	✓
POE (video)*	✓			✓	✓	✓	
POE (real-time experiment)*		✓					✓

* = only available for FPOE, # = briefing sessions for FPOE and TFC

3.3 Research Method and Design

3.3.1 Research Method

This study is a mixed-methods study that consists of quantitative and qualitative methodologies (Creswell & Plano Clark, 2007) to examine and validate how different approaches to FCs improve the SRL abilities, LA, and SPS of students with different learning abilities in science learning. Specifically, this study employed a sequential explanatory design (Creswell, 2009; Creswell & Plano Clark, 2007) to combine the strengths of both forms of research to address the following RQs:

RQ1: Can the FPOE improve students' SRL abilities, LA, and SPS in comparison with the TFC?

RQ2: Are there differences in the improvements of students' SRL abilities, LA, and SPS among different pedagogical approaches (FPOE vs. TFC vs. TC)? If yes, which is the most effective?

RQ3: Do student learning abilities (lower and higher) affect the improvements of their SRL abilities, LA, and SPS in different flipped pedagogical approaches (FPOE and TFC)?

RQ4: How and to what extent do the FPOE and TFC help students with different learning abilities to improve their SRL abilities, LA, and SPS?

Several FC reviews have suggested the importance of conducting qualitative research to support and validate quantitative studies in FC research. For instance, Seery (2015) explicitly stated that, “comparing average performances between control and experimental groups misses nuances that are already emerging from the studies shown, and examining what happens to students individually, through qualitative work or cluster analysis, will likely offer more valuable information” (p. 766). Karabulut-Ilgu et al. (2018) echoed that qualitative methodologies would “provide more in-depth understanding of learning in a flipped environment” (p. 10). Moreover, Abeysekera and Dawson (2015) suggested that, “qualitative work [on] student learning, and student experiences of the flipped classroom approach” (p. 12) is necessary for future FC research.

Therefore, quantitative data were collected and analyzed, followed by qualitative data collection and analysis. Particularly, quantitative data of the pre-test and post-test scores in SRL, LA, and SPS were collected from the students who participated in the FPOE and TFC, whereas post-test scores from the non-flipped TC were collected as historical data for quantitative analysis to address the first two RQs. Consequently, the quantitative findings were explained using the supplementary qualitative data from student interviews to address the third research question. Figure 3.6 illustrates the sequential explanatory design of this mixed-methods study.

Figure 3.6. The convergence model of triangulation for this mixed-methods research

3.3.2 Research Design

This mixed-methods research employed a non-equivalent control group pre-test–post-test design of a quasi-experiment (Campbell et al., 1963) that comprised an experimental group of FPOE (n =63) and a control group of TFC (n =61) for seven months in the S.2 (Grade 8) science subject between 2018 and 2019.

According to Kenny (1975), quasi-experimental designs should meet the following three requirements: (a) there must be a treated group X and untreated group; (b) there must be pre-treatment and post-treatment measures O; and (c) there must be an explicit model that projects over time.

Moreover, according to Jong (2017), most studies only emphasized evaluating whether the pedagogic effectiveness of the proposed FC is better than the TC, without paying too much attention to the efficacy of the FC to improve the existing constructivist approaches of teaching and learning (Jong, 2017). Jensen et al. (2015) claimed that positive findings on student learning in FCs in existing research were probably due to the active-learning style of instruction in the classroom rather than whether the lesson is flipped or not.

Therefore, this research administrated an additional control group of non-flipped TC, in which the quantitative data of the students (n =*63*) from the previous academic year (2017–2018) were obtained as historical data. The data collected were then used to compare the effectiveness of the flipped approaches, FPOE and TFC, with a non-flipped TC regarding the learning of science. It should be noted that only post-test measurements were carried out among the students in the additional control group owing to the limitation of administering pre-tests for the TC in the previous year before the start of this research. The limitations of this study are discussed in the limitations section (Section 3.8.2). Figure 3.7 illustrates the overview of the groups of different pedagogies in this research design.

Experimental group:	O	X	O
Control group:	O	Y	O
Additional control group:			O

Figure 3.7. The overview of different pedagogies in this research design

Participants in the experimental group received the treatment *X*, which involves FC learning with the incorporation of a technology-enhanced POE strategy, while participants in the control group received treatment *Y*, which involves the TFC pedagogical approach. In contrast, participants in the additional control group received no treatment of flipped learning. The pre-test and post-test are signified by *O*, which consisted of the SRL survey, school-based LA tests, and the widely adopted basic and integrated SPS tests.

3.4 Instruments

3.4.1 Online Self-Regulated Learning Questionnaire (OSLQ)

To measure the development of students' SRL abilities in the different types of FCs employed in this study, the Online Self-Regulated Learning Questionnaire (OSLQ) (Barnard et al., 2009), which has an acceptable reliability and validity was adopted. The internal consistency of scores the questionnaire was examined using Cronbach's alpha, with .92, suggesting that scores are sufficiently reliable (Barnard et al., 2009). The internal consistency of scores by subscale of the questionnaire was also examined using Cronbach's alpha, with a range from .87 to .96, suggesting that the subscale scores are sufficiently reliable (Barnard et al., 2009). Furthermore, evidence regarding the construct validity of the questionnaire was obtained using confirmatory factor analyses (Barnard et al., 2009). In this research, the overall Cronbach's alpha values of the pre- and post-surveys of the 24-item OSLQ were .918 and .919, respectively, suggesting a very high reliability of internal consistence (Cohen et al., 2007) for assessing students' SRL abilities in this study.

The OSLQ consists of 24 self-report measurement items using a five-point Likert response format developed using Zimmerman and Schunk's (2001) theoretical view on SRL. The OSLQ assesses individual SRL in blended learning, including (a) goal-setting, (b) environmental structuring, (c) help-seeking, (d) task strategies, (e) time management, and (f) self-evaluation (Barnard et al., 2009).

The main reason for the adoption of the OSLQ is that it emphasizes the measurement of students' SRL in the blended context, including both online and face-to-face learning environments. Other well-known self-report instruments, such as the MSLQ (Pintrich, Smith, Garcia, & McKeachie 1991), were originally designed for measuring students' SRL abilities in traditional face-to-face classroom learning (Reyna, 2017). Several researchers have employed the OSLQ when studying students' SRL in online and blended learning. For example, Tabuenca et al. (2015) used the OSLQ to explore graduate students' SRL on three different online courses, including psychology and geographical information system, by using their own mobile devices. Sun, Wu, and Lee (2017) also compared students' self-regulation between distanced and flipped courses on an undergraduate physics course in Taiwan using the OSLQ.

Another reason to use the OSLQ in this study is that it is more specific with fewer questions and, thus, takes less time to complete than the MSQL, which contains 81 questions with a seven-point Likert-type response format for measuring broader aspects, including student motivations and learning strategies. Such a long questionnaire with a format that consists of values ranging from ‘not at all true of me’ to ‘very true of me’ may also burden (Bradburn, 1977), lose information (La Mar Adams & Gale, 1982), and confuse Form 2 (Grade 8) respondents regarding reporting their SRL in an accurate manner.

The questions in the OSLQ were translated into Chinese, and a bilingual version of the questionnaire was developed (see Appendix 3) to minimize misinterpretation by the students. Identical pre-SRLQs and post-SRLQs were administered before and after the TFC/FPOE interventions, respectively, to investigate student gains in SRL abilities.

3.4.2 Test of Basic Process Skills in Science (BAPS) and Test for Integrated Process Skills II (TIPS-II)

In this study, both students’ BSPS and ISPS were assessed by adopting two well-known tests, namely, Test of Basic Process Skills in Science (BAPS) and Test for Integrated Process Skills II (TIPS-II).

To assess students’ BSPS, the BAPS test, which was developed by Padilla et al. (1985) and is the only research instrument designed to measure all the most widely accepted basic science process skills for elementary and middle school students, was adopted. The test is a well validated non-curriculum test that requires very little science content knowledge for successful completion (Padilla et al., 1985). Padilla et al. (1985) stated that the overall test reliability using the Kuder–Richardson Formula 20 (KR-20) was calculated as .82, suggesting very good internal consistency. Marshall (1991) further validated the BAPS using performance-based assessments, and the results indicate strong support for the convergent and discriminant validity, and hence construct validity of the BAPS instrument. In this research, the overall Cronbach's alpha value of the pre- and post-tests of the BAPS were .703 and .697, respectively, suggesting the instrument was minimally reliable (Cohen et al., 2007) for assessing students' BSPS in this study. The BAPS evaluates six basic process skills: (a) observation, (b) communication, (c) classification, (d) measurement, (e) inference, and (f) prediction via 36 multiple-choice questions with four options (Padilla et al., 1985).

To assess students' ISPS, the TIPS-II, developed by Burns et al. (1985), was adopted. The TIPS-II is an alternative and equivalent test of the Test of Integrated Process Skills (TIPS) developed by Dillashaw and Okey (1980) for middle grade and secondary students. The TIPS-II is a validated non-curriculum process skills test comprising 36 multiple-choice questions with four options. The overall internal consistency of the TIPS-II using Cronbach's alpha was measured at .86, suggesting a higher reliability than for the TIPS (Cronbach's alpha = .82) (Burns et al., 1985). In this research, the overall Cronbach's alpha value of the pre- and post-tests of the TIPS-II were .771 and .749, respectively, suggesting an acceptable reliability (Cohen et al., 2007) for assessing students' ISPS in this study. The TIPS-II measures five components of integrated process skills: (a) identifying variables, (b) identifying and stating hypotheses, (c) operationally defining, (d) designing investigation and (e) graphing and interpreting data (Burns et al., 1985).

Numerous researchers have employed these two tests in studies of students' SPS in science education. To assess students' BSPS, Ong et al. (2015) studied the difference in acquiring BSPS by gender, school location, and by grade levels among 200 upper primary school students in Perak, Malaysia with the use of BAPS. Aydogdu (2017) also adopted BAPS to investigate the relationship between students' BSPS and academic achievement among 1272 primary school students in Turkey. To assess students' ISPS, Geban, Askar, and Özkan (1992) investigated the effects of a computer-simulated experiment and problem-solving approach on students' ISPS with the use of the TIPS-II among 200 Grade 9 chemistry students in Turkey. Ong and Ruthven (2005) studied the ISPS of Form 3 (Grade 9) students between Malaysian smart and mainstream schools with the use of the Malay version of the TIPS-II. Kramer, Olson, and Walker (2018) also employed the TIPS-II to evaluate the gains of students' ISPS from online interactive tutorials designed to help undergraduate students to develop their ISPS. There are many other studies that have adopted the two SPS tests in teacher education (e.g., Chabalengula, Mumba, & Mbewe, 2012; Gezer, 2015; Silay & Çelik, 2013).

Although there is a lack of research on the adoption of the BAPS or TIPS-II in Hong Kong secondary science education, both tests cover the six categories of SPS categorized by the Hong Kong Science (Secondary 1-3) Curriculum Framework: (a) observing, measuring, and recording data, (b) comparing and classifying, (c) planning and designing, (d) experimenting, (e) interpreting data and inferring, and (f) communicating (CDC, 2016). The questions in the BAPS and TIPS-II tests were translated into Chinese and bilingual versions (see Appendix 4 and Appendix 5). Identical pre-SPS tests (including pre-BAPS and pre-TIPS-II) and post-SPS (including post-BAPS and post-TIPS-II) tests were administrated before and after the TFC/FPOE interventions, respectively, to investigate student gains in BSPS and ISPS.

3.4.3 Learning Achievement Test (LAT)

Students' LA was assessed using the final examination paper constructed by the researcher and his colleagues in the previous academic year (i.e., 2017–2018). The examination paper consists of four sections: (a) multiple-choice, (b) matching, (c) structured questions, and (d) long questions. All the questions are related to the knowledge of science (OECD, 2016; 2019a). This

LAT carries 100 marks and takes 90 minutes for students to finish. The identical pre- and post-LA tests cover topics that students have learned throughout the year, including in the FC intervention. The questions of the LAT were also translated into Chinese, and the bilingual tests were administered before and after the TFC/FPOE interventions to investigate student gains in LA (see Appendix 6). The LAT was constructed by the researcher with detailed discussion among the three experienced subject teachers (> 10 years) at the same school regarding the test's language, structure, and content to ensure that it was suitable and valid for the target students.

To ensure that the LAT was reliable, a reliability test of internal consistency, Cronbach's alpha, was performed. The overall Cronbach's alpha value of the pre- and post-tests of the LAT were .763 and .764, respectively, suggesting an acceptable reliability (Cohen et al., 2007) for assessing students' LA in this study.

3.4.4 Interview Protocol

In this study, semi-structured interviews with students were conducted to compare the quantitative findings on how the FPOE and TFC approaches helped the students with different learning abilities to improve their SRL abilities, LA, and SPS. According to Kvale (2007), the semi-structured interview

> seeks to obtain descriptions of the life-world of the interviewee with respect to interpreting the meaning of the described phenomenon; it will have a sequence of themes to be covered, as well as some suggested questions. Yet at the same time there is openness to changes of sequence and forms of questions in order to follow-up the specific answers given and the stories told by the subjects. (p. 2)

Hobson and Townsend (2010) also regarded semi-structured interviews as partly structured interview to provide more opportunities for the interviewees to talk freely about what is significant to them compared with during structured interviews. Furthermore, semi-structured interviews ensure coverage of the researcher's agenda, achieving both a breadth and depth to the interview dataset (Hobson & Townsend, 2010).

To structure the process and take careful notes during the semi-structured interviews with students, an interview protocol was developed (Creswell, 2008). The interview protocol contains (a) a header that records essential information about the interview; (b) a first 'ice-breaking' question; (c) core interview questions addressing the research question; and (d) closing comments for acknowledging and assuring the participants of the confidentially of their responses (Creswell, 2008). A series of brief and simple interview questions were prepared in a relaxed format that is suitable for the interviewees (Kvale, 2007). Appendix 7 contains the interview protocol for this study.

At the beginning of the interview, simple closed questions about the students' engagement in the out-of-class learning activities were asked to help them recall their learning experience in the FCs. Then, open-ended questions were asked to obtain more in-depth information. For example, *Q1: How long did you spend watching the videos (including the content and experimental videos) before the science lessons in general? Did you re-watch them? If yes, how many times? And why?* The closed questions can be ideal gateways to open-ended probing (Adams, 2015).

Later, more in-depth questions on how the FC (FPOE / TFC) helped improve their SRL abilities, LA, and SPS were asked. For example, *Q6: Describe and explain some strategies you have used to help you learn in the out-of-class online environment? For example, making notes, speaking aloud, etc.* Several open-ended questions about the students' learning experience in the FCs were also asked. For example, *Q7: Did you encounter any difficulties preparing online in the PowerLesson2 platform? If so, what are they? How could you overcome them?*

In addition, a linking question – *Q10*: *How can the videos and online quizzes / POE activities help you prepare for the scientific inquiries in the science lessons?* – was asked to redirect the focus of the interview from students' learning experience in the out-of-class activities toward the in-class scientific inquiry. Although the interview questions were prepared in the interview protocol at an early stage of the study, the foci of the student interviews were adjusted depending on the quantitative results of the survey and tests in this sequential explanatory research (Creswell, 2009).

3.5 Addressing the Threats of Validity and Reliability

3.5.1 Validity

There are several threats (both internal and external) to validity that need to be identified and addressed in the quantitative section of this mixed-methods study. These threats might draw inappropriate inferences from the data (Creswell, 2009).

Internal validity threats arise from the experimental procedures, treatments, or experiences of the participants that prevent us from drawing correct inferences from the data about the population (Creswell, 2009). In this study, the quasi-experimental design was controlled to a certain extent by the internal validity threats related to the participants' history, maturation, and mortality, and those related to experimental procedures including testing and instrument

(Campbell et al., 1963). For instance, both the experimental and control groups experienced the same external events within the same school to address the threat of history. Furthermore, the students in both groups had similar demographic backgrounds, such as age, sex ratios, and race, to address the threat of maturation. Moreover, the threat of mortality was avoided as there was no drop out among the participating students. Finally, the same instruments were employed for the pre-test and post-test measures to address the validity of instrumentation (Creswell, 2009).

However, selection bias still posed a considerable threat to this quasi-experimental study as there was no random assignment or selection of the participants. Regression threats might also occur if participants with extreme scores, which might regress toward the mean over time regardless of the treatment effect, are selected for the experiment (Campbell et al., 1963). Moreover, internal validity threats related to using an experimental treatment and manipulations, which involves compensatory demoralization, compensatory rivalry, and treatment diffusion (Creswell, 2009), might also occur.

Nevertheless, the employment of a historical cohort control group of TC could decrease the threats of selection, reactivity, treatment diffusion, compensatory demoralization, and compensatory rivalry (Walser, 2014). For example, there would be a minimization of the threats of reactivity to the experimental situation, in which individuals might change their performance or behavior due to the awareness of being observed (Shadish, Cook, & Campbell, 2002), because the assessment used for the historical control group was part of routine monitoring and evaluation in the school setting, and hence, considered by the students to be normal (Walser, 2014). Treatment diffusion, compensatory demoralization, and compensatory rivalry could be eliminated when using a historical control group because the FC interventions and historical

TC setting were not concurrent (Walser, 2014). In line with Shadish et al.'s (2002) discussion regarding adding design elements to strengthen the validity of a study, Walser (2014) also suggested that the use of a "historical cohort control group as a design element as part of a larger study can strengthen validity" (p. 6).

On the other hand, external validity threats that hinder generalizing the research findings to establish a causal relationship from the sample data to apply to students in other settings (Shadish et al., 2002) also need to be considered. For example, the interaction between selection and treatment, the interaction between setting and treatment, and the interaction of history and treatment might restrict generalizing the research findings to other contexts. Nonetheless, the use of a historical control might address these issues in certain extents.

In addition to the threats of internal and external validity of the quasi-experiment, the tests and data analysis of this study should also address on some other types of validity, including (a) content validity, which refers to adequate test coverage and relevance; (b) construct validity, which refers to the extent to which specific constructs can account for performance on the test (Cohen, Manion, & Morrison, 2007); and (c) statistical conclusion validity, which refers to the inferences about whether the conclusion is reasonable due to the appropriate statistical power or the compliance of statistical assumptions (Creswell, 2009; Drost, 2011). Therefore, this study employed instruments that have been validated by previous researchers, as discussed in Section 3.4.

This study made several measures based on suggestions from Creswell (2009) and Cohen et al. (2007) to address the aforementioned threats to validity:

(a) A longer time interval (i.e., seven months) between administering the measures to ensure that the students would not be familiar with the outcome of the pre-tests and remember those responses for later post-tests (addressing internal validity threat of testing).

(b) Assignment of students evenly with similar demographics, such as proportions of gender and learning ability, into the two groups of the FPOE and TFC, as well as the historical TC group (addressing internal validity threat of selection).

(c) Equal treatments, such as the same bonus marks and feedback, were provided for students in their participation in the online learning activities in the two groups of the FPOE and TFC, so that students in both groups might feel they gained benefits equally (addressing internal validity threat of compensatory demoralization).

(d) Progressive thorough discussions with the science teachers regarding the expectations of students in different groups to ensure that students in the control group (TFC) would not feel they were being devalued (addressing internal validity threat of compensatory rivalry).

(e) Separation of the groups as much as possible by (i) limiting student authority regarding accessing and communicating between different groups in the LMS; (ii) preventing disclosure and discussion of the experimental treatment in the control groups by the science teachers; and (iii) arranging different subject teachers into the FPOE and TFC groups (addressing internal validity threat of diffusion of treatment).

(f) Formation of an expert panel comprising three experienced science teachers with more than 10 years of teaching experience for checking and validating the LA test with the science content to be assessed (addressing threat of content validity).

(g) Adopting well-established instruments (i.e., OSLQ, BAPS, and TIPS-II) with validations (addressing the threat of construct validity).

(h) Translation of the instruments into a bilingual version with help of an English panel chairperson who is familiar with both English and Chinese and the subject matter in the same school as the research to ensure the validity of the instruments prior to pilot testing and to refine the instruments after the testing.

(i) Implementation of a pilot test that involved using the quantitative instruments translated into Chinese and administered with English bilingually, as well as interviews with participants in a Form 2 (Grade 8) flipped POE class (2A) in 2017–2018 (not the historical control classes) to ensure that the bilingual OSLQ, BAPS, TIPS-II, and LA tests and the proposed interview questions were valid, reliable, and practical.

(j) Analysis of quantitative data with adequate statistical power and without violating the statistical assumption (addressing the threat of statistical conclusion validity).

According to Maxwell (2013), researcher bias and reactivity caused by the influence of the researcher or the setting to an individual under study are the two main validity threats to qualitative studies. Therefore, to assure qualitative validity regarding the accuracy of the findings in this mixed-methods study, the following validity strategies (Creswell, 2009) were employed:

(a) Clarification of the possible bias the research might contain.

(b) Determining the accuracy of the interview transcripts through taking specific descriptions or themes back to the interviewees for accuracy checking.

(c) Translating the interview transcripts in Chinese into English with the help of the English panel chairperson to ensure accuracy.

(d) Assigning a peer debriefer to help review and account for the qualitative findings.

3.5.2 Reliability

According to Cohen et al. (2007), reliability is concerned with the precision and accuracy of a study. Reliability is also "essentially a synonym for dependability, consistency and replicability over time, over instruments and over groups of respondents" (Cohen et al., 2007, p. 199).

For the quantitative tests in this study, all the adopted instruments, including the OSLQ, BAPS, and TIPS-II, already had established very high internal consistencies with a reliable Cronbach's alpha (> 0.8) (Cohen et al., 2007; see Section 3.4). The corresponding internal consistencies of the adopted instruments in this current study were also calculated to ensure their high reliability (see Section 4.2.1). The procedure used for the quantitative data collection was also assessed. For example, the consistency of the marking of the tests was addressed by follow-up checking by another subject teacher.

To ensure that the qualitative interviews were reliable, researcher bias has been avoided as much as possible (Yin, 2009). The interview procedures were documented in detail (see Section 3.6.3) and the following reliability procedures (Gibbs, 2007) were employed:

(a) Maintaining a good rapport between interviewer and interviewee (Cohen et al., 2007).
(b) Piloting interviews with students to help develop reliable codes for the current study.
(c) Checking the interview transcripts several times to ensure no mistakes were made during the transcription process from the recorded audios (Creswell, 2009).
(d) Comparing the interview data with the codes and written memos from interview protocols several times to ensure there was no shift in the definition and meaning of codes during the categorizing process (Creswell, 2009).

3.6 Data Collection

In this sequential, explanatory, mixed-methods study (Creswell, 2009), quantitative data from the questionnaire survey and the tests were collected and analyzed before collecting and analyzing the qualitative data from the student interviews. The purpose of this design was to build on the quantitative findings from the initial phase to inform the secondary qualitative collection and analysis, leading to an in-depth examination and explanation of the quantitative results (Creswell & Plano Clark, 2007). Table 3.4 shows an overview of the data sources that address the RQs.

Table 3.4
The data sources that address the RQs

Data Source	Type	Description	RQ1	RQ2	RQ3	RQ4
Current cohort (2018–2019)						
Pre- and post-survey of SRL	Quantitative	Measure students' SRL abilities before and after the interventions	√	√	√	
Pre- and post-tests of SPS	Quantitative	Measure students' SPS before and after the interventions	√	√	√	
Pre- and post-tests of LA	Quantitative	Measure students' LA before and after the interventions	√	√	√	
Interviews with students	Qualitative	Interviews with students about their SRL abilities, LA, and SPS	√	√	√	√
Historical cohort (2017–2018)						
3rd Term examination	Quantitative	Measure students' LA in the historical control group		√		
Post-tests of SPS	Quantitative	Measure students' SRL abilities in the historical control group		√		
Post-survey of SRL	Quantitative	Measure students' SRL abilities in the historical control group		√		

The procedure for ethical approval, the schedule for the administering of instruments in quantitative data collection, and the procedure for qualitative data collection from student interviews are described in the following sections.

3.6.1 The Procedure for Ethical Approval

The student participation in this research required thoughtful ethical consideration to assess the potential for risk toward the participants (Creswell, 2009; Creswell & Plano Clark, 2007). To ensure the research was conducted according to the highest standards of ethical consideration to safeguard the physical, psychological, and intellectual comfort of the participants, an independent ethical review in accordance with the Education University of Hong Kong's (EdUHK) *Guidelines on Ethics in Research* was applied prior to the data collection on 11 September 2018. This ethical review, which includes approval from the Human Research Ethics Committee (HREC) and the endorsement of the principal supervisor, is a compulsory requirement for any research postgraduate project involving human data under the auspices of the university. Appendix 8 contains the approval of the ethical review from the HREC granted for the research period between 9 October 2018 and 28 June 2019.

The permission to collect data was obtained from the school and the individuals involved, including the target population of students, the subject teachers of the classes, and the principal of the school. Since the target participants were mainly aged 13, the consent forms required signatures from both the students and their parents/guardians. Appendix 9, Appendix 10, and Appendix 11 contain these consent forms, which include clear descriptions of the research background and methodologies, potential risks, guarantee of confidentiality of the participants, and how the results will be potentially disseminated.

3.6.2 Quantitative Data Collection

Quantitative data collection was conducted once the ethical approval had been granted from the university. For the current cohort, the pre-scores of the OSLQ, BAPS, TIPS-II, and LAT of all the students in different intervention groups were collected in science lessons during the period between 11 October 2018 and 16 October 2018. In particular, the 10-minute OSLQ was administered in a single lesson, the 30-minute BAPS and 35-minute TIPS-II were administered in a double lesson, and the 90-minute LAT was arranged for an afternoon double lesson since extra time after school was required. A laboratory technician was assigned to monitor the tests without the presence of subject teachers to minimize any teacher influence. Similarly, the post-scores of the OSLQ, BAPS, TIPS-II, and LAT were collected during the period between 3 May 2018 to 10 May 2018 after the flipped learning interventions.

For the historical cohort, only the post-scores of the OSLQ, BAPS, TIPS-II, and LAT were collected. Particularly, the post-scores of the LAT among the target historical students, who had already participated in the final examination in 2017–2018, were collected by accessing the data from the school intranet database system, WebSAMS, with permission from the school. On the other hand, the students' post-scores of the OSLQ, BAPS, and TIPS-II of the historical cohort were collected through measurements in the current year during the period between 11 October 2018 and 16 October 2018, at which time these students were in Form 3. Following the FC interventions, the students' post-scores of the OSLQ, BAPS, TIPS-II, and LAT of the current cohort were collected between 16 May 2019 and 23 May 2019. The same laboratory technician was assigned to monitor to ensure as little variation as possible to avoid bias being introduced (Creswell, 2009).

The students' five-point Likert responses from the OSLQ were directly input by the researcher into a Microsoft Excel file for data storage. The students' multiple-choice answers from the BAPS and TIPS-II and the final marks of the LAT were input in that Microsoft Excel file for data storage. The researcher was responsible for the data entry and double-checking. To ensure the confidentiality of the participants, all identifying information from the data were removed and stored confidentially and separately, with any links between identifying information and the data being through codes only. The Microsoft Excel file was password-protected and stored in a password-protected computer, and the original, anonymized hard copies of the OSLQ questionnaires, and the BAPS, TIPS-II, and LAT tests were stored in a locked room inside the science laboratory and will remain there until two years past publication.

3.6.3 Qualitative Data Collection

In this sequential, explanatory, mixed-methods study, the primary emphasis is on the quantitative aspects (Creswell & Plano Clark, 2007). The qualitative data play a supplementary role illustrating and explaining the quantitative results (Creswell, 2009).

Semi-structured interviews with students on their learning journey in different FCs (i.e., FPOE and TFC) were carried out after the completion of the FC interventions, as well as the collection and preliminary analysis of qualitative data during the period between 24 June 2018 and 28 June 2018. The duration of each interview was at least 30 minutes. A purposeful sampling (Creswell & Plano Clark, 2007) technique was employed for the students in the current cohort for interview to involve interviewees with different learning outcomes from the FC interventions. Subject to the quantitative findings, (a) interviewees with an overall gain in SRL abilities, SPS, and LA, and (b) interviewees with negative or no effect on the measurements were selected. If all students displayed positive improvements in a group, the interviewees with the most gain and least gain were selected. Table 3.5 illustrates the interviewee sampling, the number of interviewees, and the assignment of identifiers for the interviewees in this study.

Table 3.5
Interviewee selection

Group / class (learning ability)	Impacts of FC interventions*	Number of interviewees (%)	Identifiers
FPOE / 2A (higher)	Positive	2/32 (6.25%)	FPOE-H-P-1, FPOE-H-P-2
	None / negative	2/32 (6.25%)	FPOE-H-N-1, FPOE-H-N-2
TFC / 2B (higher)	Positive	2/31 (6.45%)	TFC-H-P-1, TFC-H-P-2
	None / negative	2/31 (6.45%)	TFC-H-N-1, TFC-H-N-2
FPOE / 2C (lower)	Positive	2/31 (6.45%)	FPOE-L-P-1, FPOE-L-P-2
	None / negative	2/31 (6.45%)	FPOE-L-N-1, FPOE-L-N-2
TFC / 2D (lower)	Positive	2/30 (6.67%)	TFC-L-P-1, TFC-L-P-2
	None / negative	2/30 (6.67%)	TFC-L-N-1, TFC-L-N-2

*subject to the quantitative findings

In summary, 16 interviewees participated (16 out of 124, 12.9%), which is an acceptable number of samples to supplement the quantitative findings (Creswell & Plano Clark, 2007). A unique identifier was assigned to each interviewee to ensure anonymity. The interviews were conducted in Chinese and audio-recorded into sound files using an electronic recorder. The interview protocol was used to guide the interviews. The conversation audios between the researcher and interviewees were stored in a password-protected computer. Transcription of the recorded audios was then carried out and the data translated into English with the help of the English panel chairperson for reporting purposes. Finally, the qualitative data were stored in Microsoft Word files and saved in a password-protected computer. The interviewees checked the accuracy of the transcriptions to ensure validity.

3.7 Data Analysis

3.7.1 Quantitative Data Analysis

3.7.1.1 The Rationale for Choosing Statistical Analysis

Regarding the method of data analysis in this non-equivalent control group pre-test–post-test design of a quasi-experiment (Campbell et al., 1963), the pre- and post-scores from the OSLQ, BAPS, TIPS-II, and LAT were collected from the students in the current cohort, whereas only the post-scores were collected from the students in the historical cohort. To address the first two quantitative RQs, (a) a paired sample *t*-test between the pre-scores and post-scores, (b) independent sample *t*-tests on the pre-scores, post-scores, and gain scores, and (c) between-subjects analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) of the gain scores and post-scores were employed in different circumstances with the following rationales.

Since only analysis of post-test scores without considering the pre-test scores may result in analysis bias and erroneous conclusion (Bonate, 2000), independent sample *t*-tests on the gain scores, which have often been suggested to be used to measure the treatment effects in the non-equivalent control group design with the selection based on a stable group of an intact class (Kenny, 1975), were used in this research.

In addition, data analysis using the independent sample *t*-test for gain scores between groups was used instead of repeated measures of ANOVA with a fixed-effects group factor and analysis of covariance (ANCOVA) / multivariate analysis of covariance (MANCOVA) using pre-test scores as a covariate with a fixed-effect group factor for the following reasons:

First, repeated-measures ANOVA with a fixed-effects group factor and independent sample *t*-test of the difference between gain scores from two independent groups are said to be equivalent (Smolkowski, 2019). Anderson et al. (1980) notes that, "with only two data points, the repeated-measures ANOVA is mathematically equivalent to the simple gain score" (p. 238). For ease of data interpretation without considering the treatment X test-occasion interaction, the independent sample *t*-test of gain scores between groups is preferable (Bonate, 2000).

Second, the choice between analysis of gain scores and ANCOVA/MANCOVA should depend on the research question (Fitzmaurice, Laird, & Ware, 2004). Specifically, ANCOVA/MANCOVA answer RQs that test for the difference of post-test, given that participants begin with the same score. However, *t*-tests of gain scores answer RQs that focus on the difference in gains of scores, on average, between different groups. Hence, this research employed the latter method to examine the differences in gains of students' SRL abilities, LA, and SPS between the FPOE and TFC pedagogical approaches.

Third, several studies recommended the use of ANCOVA/ MANCOVA only for the analysis of data in randomized experimental designs (Fitzmaurice et al., 2004; Oakes & Feldman; 2001). In the absence of randomization, in which baseline differences between groups exist in this quasi-experimental research that consists of classes with different learning abilities, gain scores analysis is preferred for yielding less-biased estimates (Oakes & Feldman, 2001). Huck (2008) stressed that ANCOVA might not be applicable for the non-equivalent control group design because the population means on the covariate cannot be assumed to be equal and, consequently, the adjusted means for the post-test could be biased (Gliner, Morgan, & Harmon, 2003).

3.7.1.2 Data Analysis Procedures

The data analysis using the aforementioned statistical methods was proceeded by the IBM Statistical Package for the Social Sciences (SPSS) version 25, which is a powerful software package often used for statistical analysis (Cohen et al., 2007; Field, 2009). All the data stored in the Microsoft Excel file were imported into the SPSS with the defining of variables needed for the analysis. Data transformation of the students' multiple-choice answers in the BAPS and TIPS-II into item and subscale marks was also conducted. The gain scores of the OSLQ, BAPS, TIPS-II, and LAT were computed using SPSS. Reliability tests regarding internal consistency (i.e., Cronbach's alpha) of the quantitative instruments (OSLQ, BAPS, and TIPS-II) in the current study were also carried out.

As assumption of the parametric data is necessary for the inferential statistical analysis used in this study, checks for the assumptions of (a) normality, via visualizations of data in the form of histograms and Q-Q plots, and (b) homogeneity of variance, using Levene's test, were conducted in SPSS before the inferential analysis (Field, 2009).

3.7.1.3 Statistical Analysis for Addressing the Research Questions

To answer the first two research questions (RQ1 and RQ2), below, different inferential statistical analyses were employed.

RQ1: Can the FPOE improve students' SRL abilities, LA, and SPS in comparison with the TFC?

RQ2: Are there differences in the improvements of students' SRL abilities, LA, and SPS among different pedagogical approaches (FPOE vs. TFC vs. TC)? If yes, which is the most effective?

RQ1 investigates the improvements of students' SRL ability, LA, and SPS by different flipped approaches in the current cohort. On the other hand, RQ2 investigates student improvements between all pedagogies in both the current and historical cohorts.

For the analysis of the quantitative data addressing the first research question (RQ1), paired sample *t*-tests between pre- and post-scores were carried out to determine how different flipped pedagogies (FPOE and TFC) could improve students' SRL abilities, LA, and SPS. Independent sample *t*-tests on the gain scores were carried out to examine whether there were differences of the SRL abilities, LA, and SPS between the two flipped pedagogies following the interventions.

Since no pre-scores of the students' SRL abilities, LA, and SPS were collected in the TC in the historical cohort, ANOVAs/MANOVAs analysis using gain scores was not feasible for addressing the second research question (RQ2). Hence, ANOVAs/MANOVAs on only the post-scores of the students' SRL abilities, LA, and SPS were conducted to examine the effectiveness of the flipped pedagogies (FPOE/TFC) in comparison with the TC. Figure 3.8 illustrates the quantitative data analysis of the *t*-tests and ANOVA to address the two RQs. Caution is advised when discussing the quantitative findings of the second research question (RQ2) regarding the statistical power because only post-scores were used for the ANOVA.

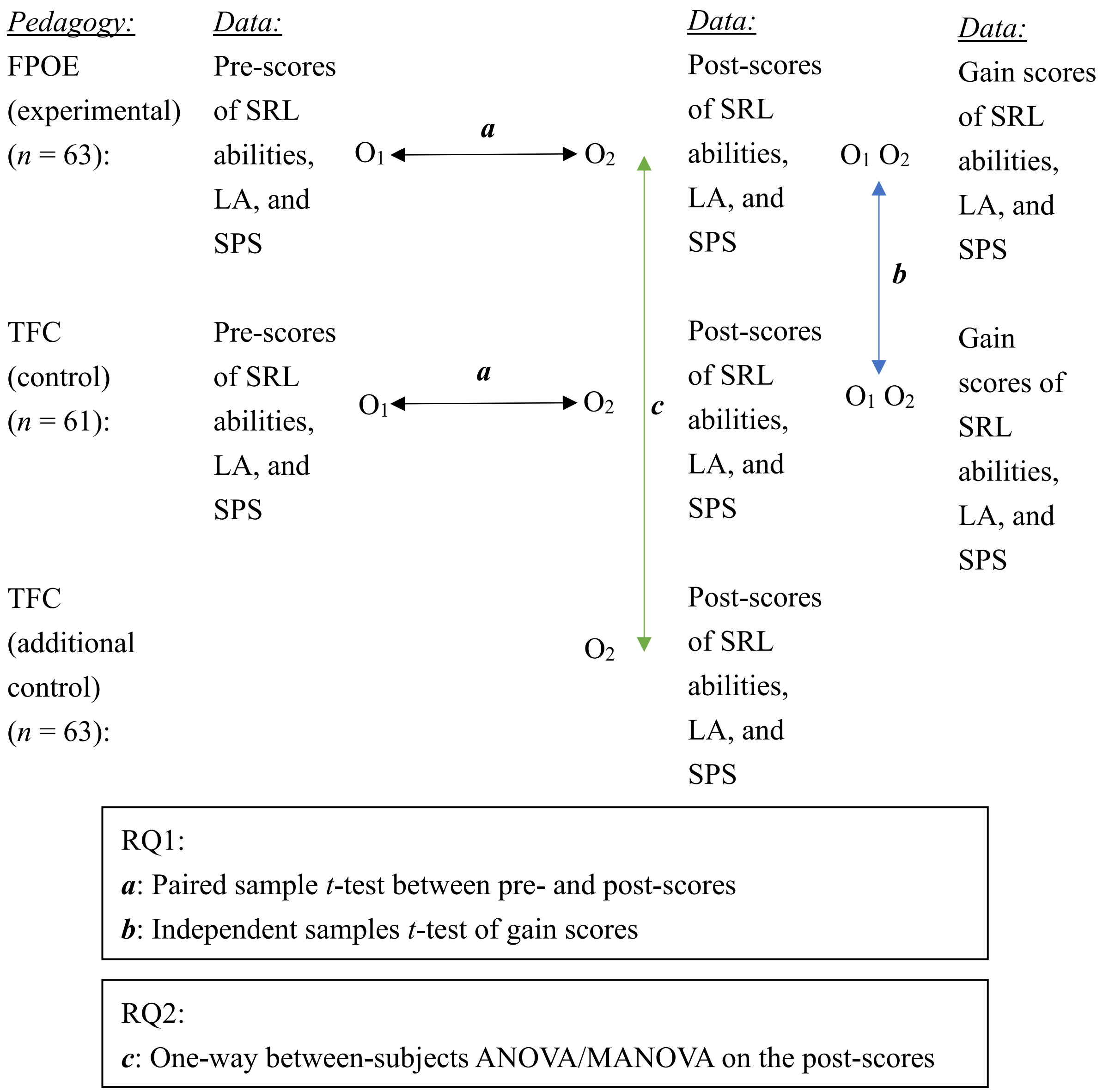

Figure 3.8. An overview of quantitative data analysis for addressing RQ1 and RQ2

RQ3: Do student learning abilities (lower and higher) affect the improvements of their SRL abilities, LA, and SPS in different flipped pedagogical approaches (FPOE and TFC)?

Regarding the third research question (RQ3), above, independent sample *t*-tests on gain scores were carried out to examine whether there were differences of the SRL abilities, LA, and SPS between the students with higher and lower abilities in different flipped pedagogies. In addition, two-way between-subjects ANOVAs/MANOVAs of the students' gain scores by learning ability and flipped pedagogy were conducted to investigate whether there was any interaction effect between learning ability and flipped pedagogy regarding student improvements of the SRL abilities, SPS, and LA. Figure 3.9 illustrates the aforementioned quantitative data analysis.

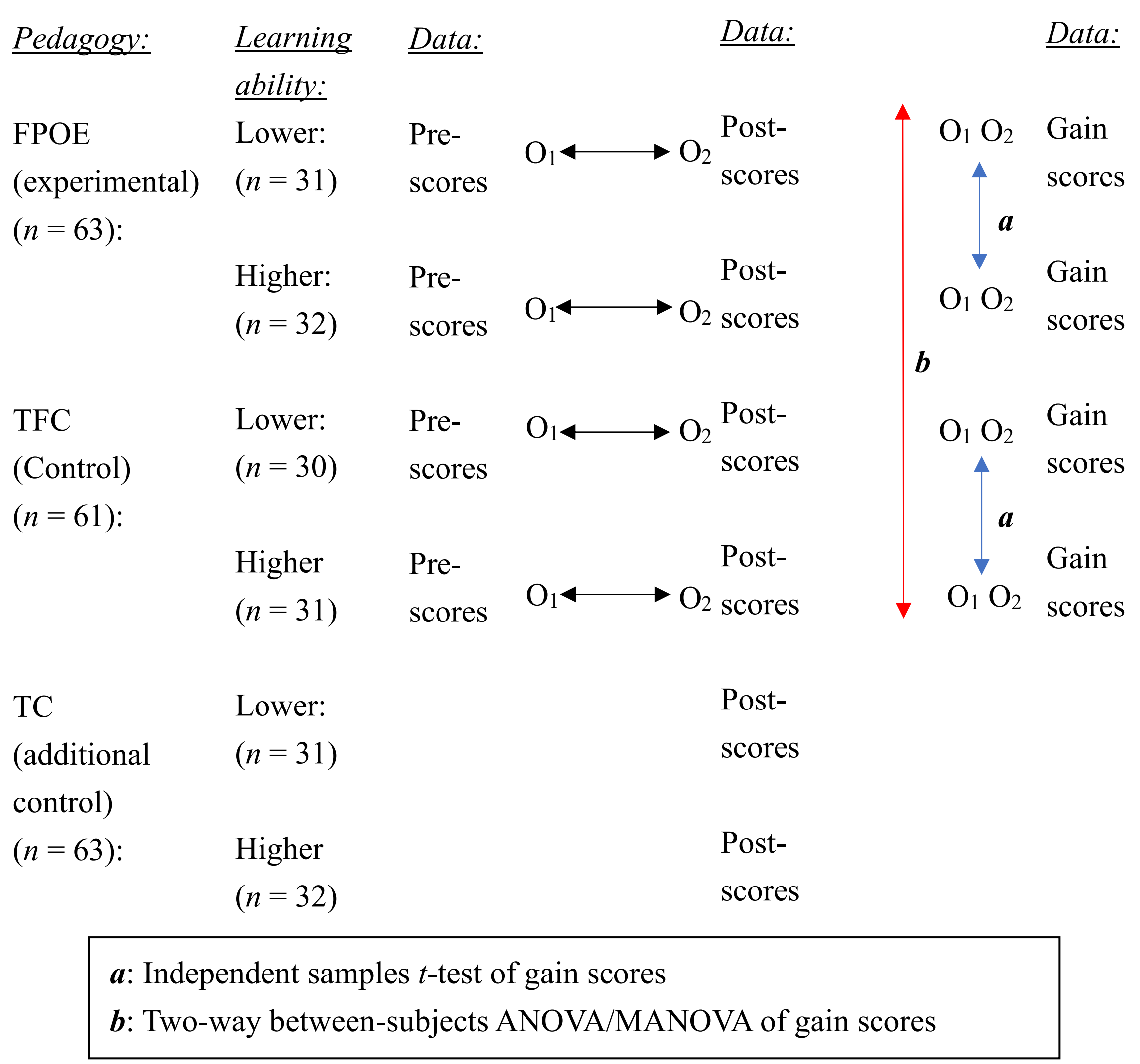

Figure 3.9. An overview of quantitative data analysis for addressing RQ3

3.7.2 Qualitative Data Analysis

Qualitative data analysis was conducted following the interviews with the students according to the aforementioned purposeful sampling. The main purpose of the qualitative data analysis was to find in-depth and detailed evidence to explain the quantitative findings, and hence, address the fourth research question (RQ4) in this study:

RQ4: How and to what extent do the FPOE and TFC help students with different learning abilities to improve their SRL abilities, LA, and SPS?

Data from the interview transcripts stored in Microsoft Word files were imported into NVivo 12, which is a qualitative data analysis computer software package often used by qualitative scholars to organize categories and analyze text-based information (Cohen et al., 2007; Maxwell, 2013). Then, categorizing analysis was conducted with (a) the intensive identification of segments from the interview transcripts and (b) the categorizing of the segments into coding categories that address RQ4.

A set of organization categories, often called topics, covering broad areas or issues related to this study were established prior to the interviews (Maxwell, 2013). The topics included (a) benefits of different flipped pedagogical approaches in terms of SRL abilities, (b) SPS, (c) LA, and (d) the challenges of different flipped pedagogical approaches in this study.

Theoretical categories, which could be regarded as the sub-categories or themes of the organizational categories, were also derived from developed frameworks from other studies (Maxwell, 2013). In particular, the topic of SRL abilities might include themes of (a) goal-setting, (b) environmental structuring, (c) help-seeking, (d) task strategies, (e) time management, and (f) self-evaluation (Barnard et al., 2009). The topic of SPS might consist of the themes of (a) observation, (b) communication, (c) classification, (d) measurement, (e) inference, (f) prediction (Padilla et al., 1985), (g) identifying variables, (h) identifying and stating hypotheses, (i) operationally defining, (j) designing investigation, and (k) graphing and interpreting data (Burns et al., 1985). The topic of benefits on improving LA might consist of the themes of (a) sufficient time for activities, (b) learning of new knowledge, (c) real-time feedback (Lo, Hew, & Chen, 2017), and (d) better management of cognitive load (Abeysekera & Dawson, 2015). Finally, the topic of challenges of the flipped pedagogies might include student-related, faculty-related, and operation-related challenges (Betihavas et al., 2016).

Finally, open coding of data would be conducted if substantive categories were inductively generated from the students' own concepts and insights (Maxwell, 2013). The analyses of the data were displayed with the frequency of the themes obtained from the interview and with representative student quotes for different classifications of the group (i.e., flipped pedagogical approaches [FPOE / TFC] and learning abilities [lower / higher]). Matrices were organized to present and further develop the findings from the content analysis. Figure 3.10 shows an overview of the data collection and analysis procedures in this research.

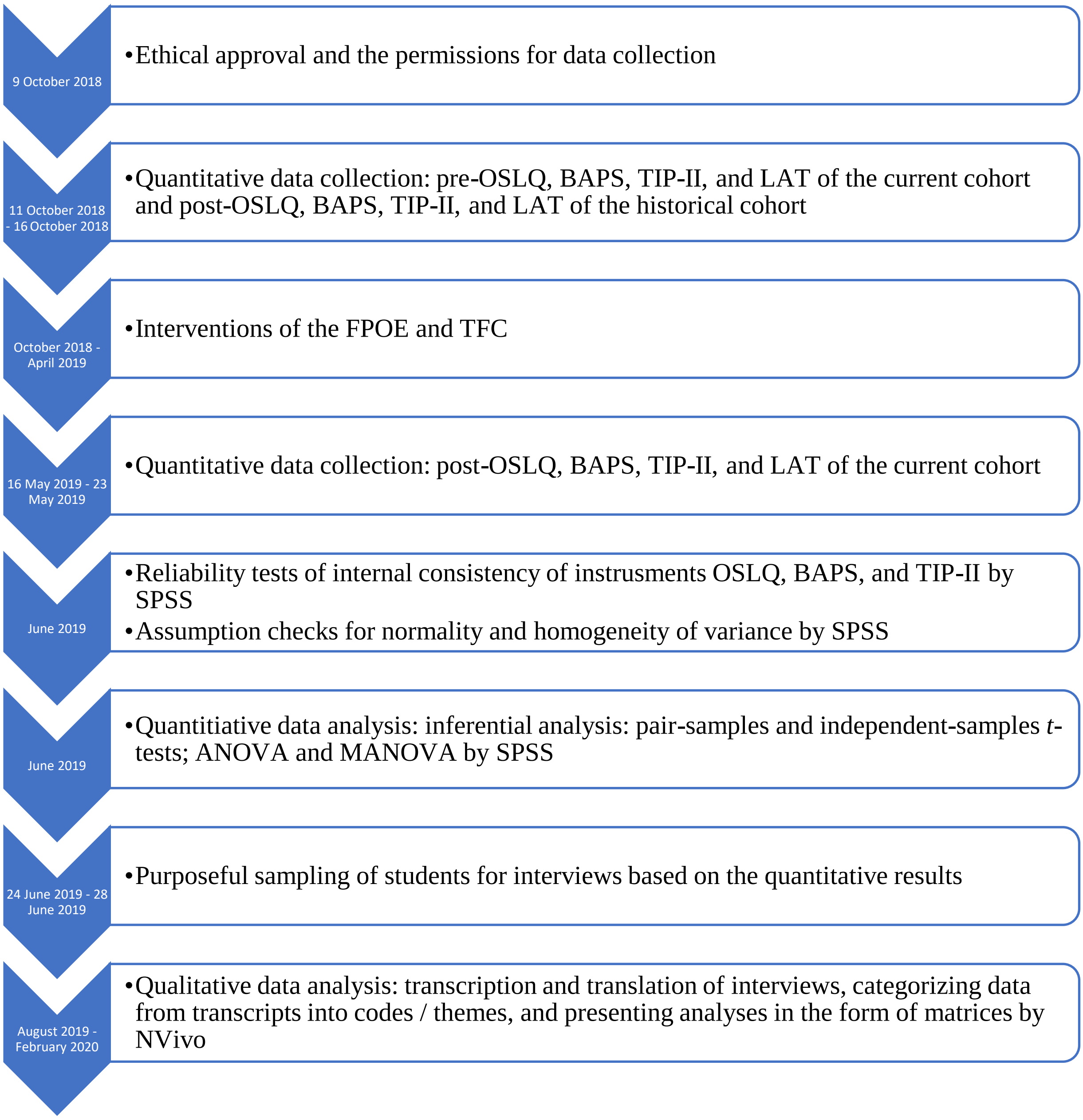

Figure 3.10. An overview of the data collection and analysis procedures

3.8 Ethical Issues

This study was conducted with the anticipation of different ethical issues arising from the data collection and analysis.

As mentioned in the section on data collection (Section 3.6), an ethical review was undertaken and approved by the HREC of the university, and agreements regarding data collection were obtained from the school and the participants. Moreover, the researcher, who was also the subject teacher of the participants, was very aware of the workloads of the flipped learning interventions on his students; hence, a lot of and equal amount of guidance, such as briefing sessions on the purpose of the study, and workshops on the use of LMS for the FCs, were provided for the students in both the FPOE and the TFC. The researcher was also cognizant that the tests and interviews might be stressful for the students; therefore, a friendly rapport between the researcher and the participants, the administering of the tests by a third person, and a thoughtful explanation on the use and confidentiality of the data were provided. All the students voluntarily participated in the study and could withdraw at any time without consequence. Incentives for the students to complete the survey, tests, and interviews were avoided.

The ethical issues that emerged during both the quantitative and qualitative data analyses were anticipated. For instance, the anonymity of students was protected by assigning codes in the quantitative data and identifiers in the interview transcripts. The analyzed and interpreted data will only be kept for two years before being fully discarded to avoid other individuals accessing them for inappropriate use (Creswell, 2009). The researcher carried out strategies to ensure an accurate interpretation of the data via a debriefing of the study and the checking of the transcripts with the interviewees (Creswell, 2009). Finally, details of the research method and design, and the procedures of data collection and analysis are all explicitly described, so that the credibility of this study can be determined by other researchers (Creswell, 2009).

3.9 Summary

This chapter outlined the research context, including the backgrounds of the participants, the designs of the pedagogical approaches (FPOE, TFC, and TC), and how the FCs were incorporated into the school curriculum. In total, 187 Form 2 (Grade 8) students in a Hong Kong secondary school participated in the study.

The mixed-methods approach and the non-equivalent control group pre-test–post-test design of a quasi-experiment were also described and explained in detail. Quantitative findings from the OSLQ survey and the BAPS, TIPS-II, and LAT tests were used to guide the sequential student interviews (*n* = 16). The features of the well-established instruments used in this study were provided, with descriptions of why they were adopted or developed. The validity and reliability of the instruments were reported, and the threats of validity and reliability regarding the research were discussed.

Finally, this chapter explained the data collection and analysis procedures comprehensively. Important ethical issues of this study were also addressed.

Chapter 4: Results

4.1 Introduction

This chapter presents the findings from the analysis of both the quantitative and qualitative data to address the four RQs. For the quantitative findings, the data from the OSLQ survey and the LAT, BPAS, and TIPS-II tests were analyzed using descriptive and inferential statistics to address the first two RQs (Section 4.2). The results from the quantitative analysis were used to guide the sampling of students for the sequential interviews to obtain more in-depth explanations of the quantitative findings in this sequential, mixed-methods research. For the qualitative data, all the student interviews were transcribed for content analysis to address the third research question (Section 4.3). A summary of the quantitative and qualitative results is provided at the end of this chapter (Section 4.4). Table 4.1 summarizes the numbers and type of data collected for the analyses.

Table 4.1
Summary of the collected quantitative and qualitative data for analysis

Group (pedagogy)	*N(Total)* (Male: Female)	Class (ability)	*N(Total)* (Male: Female)	Quantitative data	Test source	Qualitative data	*N(Total)* (Male: Female)
Experimental (FPOE)	63 (29:34)	2A (higher)	32 (15:17)	OSLQ, BAPS, TIPS-II	Pre/ Post	Interview	4 (2:2)
		2C (lower)	31 (14:17)	OSLQ, BAPS, TIPS-II	Pre/ Post	Interview	4 (2:2)
Control (TFC)	61 (34:27)	2B (higher)	31 (18:13)	OSLQ, BAPS, TIPS-II	Pre/ Post	Interview	4 (2:2)
		2D (lower)	30 (16:14)	OSLQ, BAPS, TIPS-II	Pre/ Post	Interview	4 (2:2)
Historical control (TC)	63 (32:31)	2B (higher)	32 (14:18)	OSLQ, BAPS, TIPS-II	Post	Nil	Nil
		2C (lower)	31 (18:13)	OSLQ, BAPS, TIPS-II	Post	Nil	Nil

4.2 Quantitative Findings

4.2.1 Assumption Checking for the Normality of the Data

To ensure the normality of the quantitative data for the subsequent parametric tests, frequency distributions are a useful method for examining the shape of a distribution (Field, 2009). By visualizing the data for different groups (i.e., pre- and post-scores in FPOE/TFC) in histograms and P-P plots, it was found that most of the subscale scores were normally distributed. Figure 4.1 displays a typical example of normally distributed data (post-scores of the measurement subscale of the BAPS in a TFC) visualized in the histograms and P-P plots.

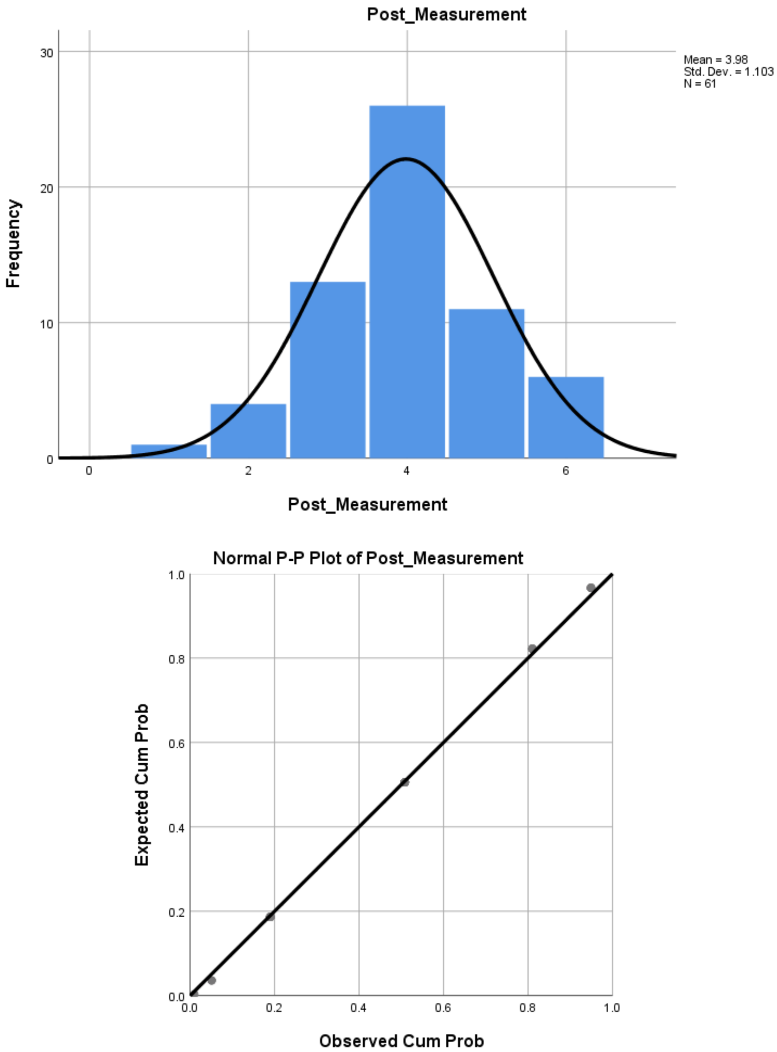

Figure 4.1. An example of normally distributed data visualized in a histogram and a P-P plot

To confirm the assumption without subjectivity, skewness and kurtosis were used to test the normality of the pre-, post-, and gain scores of the subscales (n = 63) in different pedagogical groups. The results indicate that the skewness and kurtosis values of almost all subscales in the FPOE group were between -1.343 and 0.557, whereas those in the TFC were between -1.886 and 1.322. According to George and Mallery (2010), skewness and kurtosis values that lie between -2.00 and 2.00 are an acceptable normality range of data (George & Mallery, 2010). Thus, the data of the pedagogical groups are likely normally distributed.

For the post-scores of the subscales (n = 21) in the historical TC group, the skewness and kurtosis values of all subscales were within the range of -1.101 and 1.392, suggesting an acceptable range of normality of the data (George & Mallery, 2010). Hence, the assumption of data with a normal distribution was also met for the later inferential statistical tests.

4.2.2 The Identification of Outliers and Their Treatments

According to Tabachnick and Fidell, (2013), any data with z-scores < -3.29 or > 3.29 could be identified as extreme. By computing the z-scores of the data, including the pre-, post-, and gain scores of different subscales, one extreme outlier, with a z-score of 4.571, was identified in the pre-LA scores of a student in the TFC group.

Further investigation of the outlier was conducted by visualizing the data in a boxplot (see Figure 4.2). The score of the outlier in the Excel file and that imported in the SPSS was also checked to confirm that it was not caused by human error during data collection, recording, or entry (Osborne, 2007).

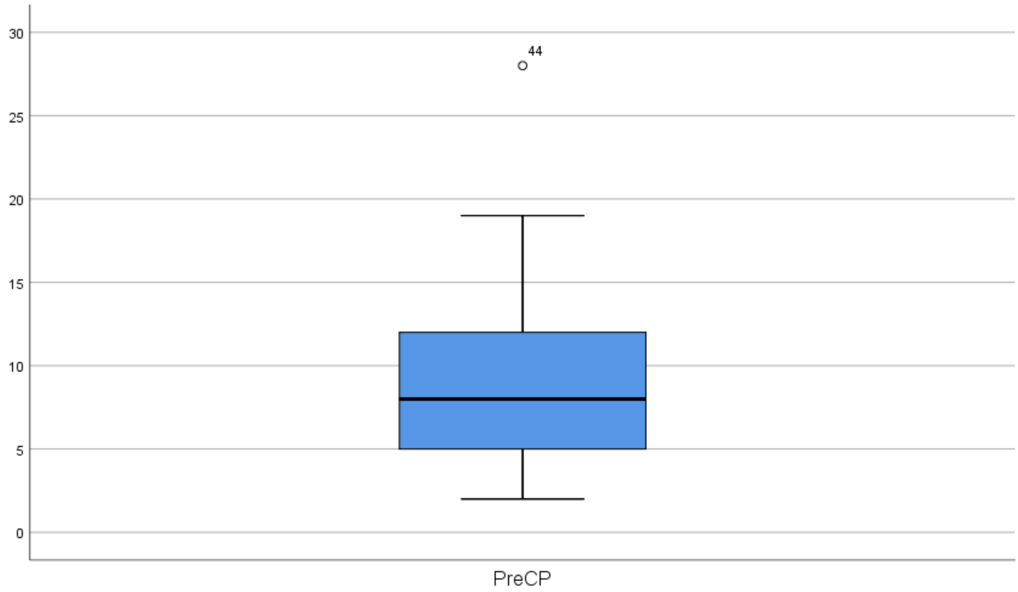

Figure 4.2. Boxplot displaying the pre-scores of the students' LA of the TFC group with an outlier

This outlier was not removed since it was found to be a legitimate case sampled from the correct population in this study (Osborne, 2007). To prevent the outlier from affecting the subsequent inferential tests, the score could be changed to be one unit above the next highest score in the dataset or to be the mean adding three times of the standard deviation (Osborne, 2007). In this case, the extreme outlier of LA = 28 was replaced by LA = 20. Figure 4.3 displays the boxplot and the pre-scores of LAT of the TFC group after the truncation and change of the identified outlier.

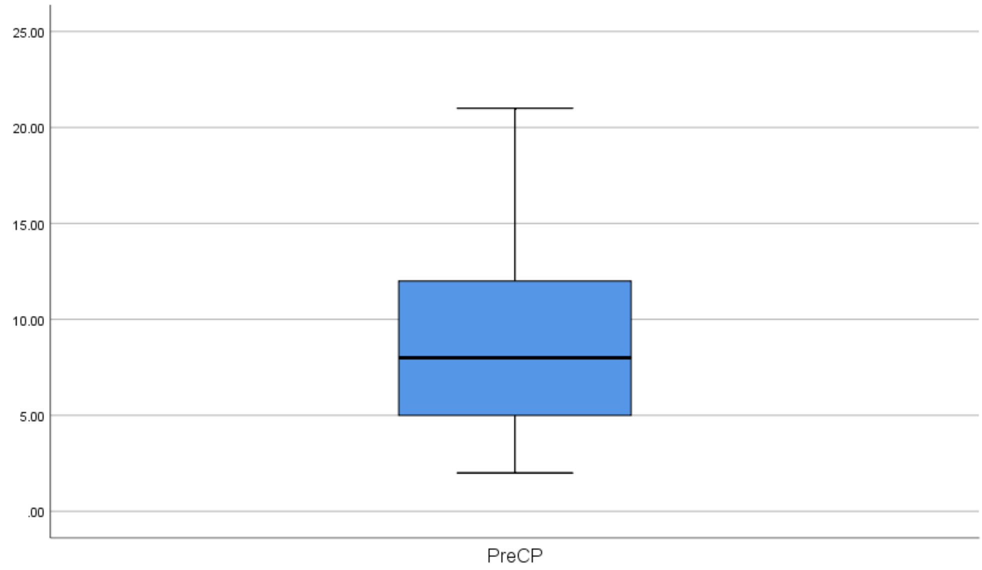

Figure 4.3. Boxplot displaying the pre-scores of the students' LA of the TFC group after treating the outlier

Moreover, the data were further assessed for multivariate outliers using a Mahalanobis distance test (Tabachnick & Fidell, 2013) in SPSS. However, no multivariate outlier was identified.

4.2.3 Statistical Analysis Addressing the First Research Question (RQ1)

To address the first research question (RQ1), which focuses only on the flipped pedagogical approaches, paired sample *t*-tests between pre-test and post-test scores and independent sample *t*-tests of gain scores were carried out. Table 4.2 shows the descriptive statistics of the quantitative data collected for addressing RQ1.

Table 4.2

Descriptive statistics of the quantitative data collected to address RQ1

	FPOE				TFC			
	Posttest		Pretest		Posttest		Prettest	
SRL ability	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Goal setting	3.420	.555	3.314	.602	3.143	.500	3.144	.699
Environmental structuring	3.663	.666	3.583	.713	3.435	.635	3.525	.727
Task strategies	3.056	.708	2.992	.783	2.848	.673	2.873	.786
Time management	3.328	.621	3.106	.703	3.071	.645	2.962	.819
Help seeking	3.337	.587	3.270	.695	3.205	.567	3.189	.811
Self-evaluation	3.425	.644	3.254	.696	3.172	.585	3.086	.758
Overall SRL	3.371	.522	3.254	.547	3.146	.461	3.130	.576
LA	46.683	13.171	8.587	3.774	45.951	11.151	8.557	4.288
Observation	4.71	1.142	4.83	1.056	4.85	1.181	5.00	1.017
Communication	4.49	1.378	4.51	1.469	4.34	1.377	4.69	1.104
Classification	4.84	1.096	4.57	1.316	4.77	1.039	4.95	1.007
Measurement	4.44	1.012	3.68	1.189	3.98	1.103	3.66	1.078
Prediction	4.02	1.129	3.71	1.069	4.13	1.103	3.95	1.175
Inference	4.63	1.248	4.51	1.105	4.84	1.003	5.00	1.125
Overall BSPS	27.14	4.280	25.81	4.624	26.92	4.428	27.25	3.931
Identifying variables	6.86	2.752	4.75	2.279	6.75	2.560	5.28	2.169
Stating hypotheses	4.54	2.154	3.00	1.769	3.97	1.844	3.70	2.068
Operational defining	2.94	1.655	2.32	1.424	3.08	1.584	2.62	1.714
Designing investigation	1.78	.771	1.30	.835	1.80	.703	1.33	.769
Graphing and interpreting data	4.32	1.354	3.38	1.419	3.84	1.344	3.49	1.312
Overall ISPS	20.43	5.721	14.75	5.255	19.44	5.387	16.43	5.798

4.2.4.1 Self-Regulated Learning (SRL) Abilities

Paired sample t-tests between the pre- and post-scores of SRL abilities in different flipped pedagogies (FPOE and TFC)

Paired sample *t*-tests were employed to examine whether the FPOE pedagogical approach made a difference to the students' SRL abilities. Paired sample *t*-tests were also employed to examine whether the TFC pedagogical approach made a difference to the students' SRL abilities. The results are summarized in Table 4.3.

Table 4.3
Summary of the results for paired sample t-tests on SRL abilities at different flipped pedagogies

Measurement	Flipped pedagogy											
	FPOE						TFC					
SRL ability	Posttest		Pretest		*t*	*Sig. (2-tailed)*	Posttest		Prettest		*t*	*Sig. (2-tailed)*
	M	*SD*	*M*	*SD*			*M*	*SD*	*M*	*SD*		
Goal setting	3.420	.555	3.314	.602	1.308	.196	3.143	.500	3.144	.699	-.011	.992
Environmental structuring	3.663	.666	3.583	.713	.740	.462	3.435	.635	3.525	.727	-.744	.460
Task strategies	3.056	.708	2.992	.783	.570	.571	2.848	.673	2.873	.786	-.214	.831
Time management	3.328	.621	3.106	.703	2.141	.036	3.071	.645	2.962	.819	1.044	.300
Help seeking	3.337	.587	3.270	.695	.661	.511	3.205	.567	3.189	.811	.167	.868
Self-evaluation	3.425	.644	3.254	.696	1.651	.104	3.172	.585	3.086	.758	.959	.341
Average SRL ability	3.371	.522	3.254	.547	1.637	.107	3.146	.461	3.130	.576	.222	.825

Figure 4.4 and Figure 4.5 show bar charts illustrating the mean scores of the average SRL ability and its subscales in the FPOE and the TFC, respectively.

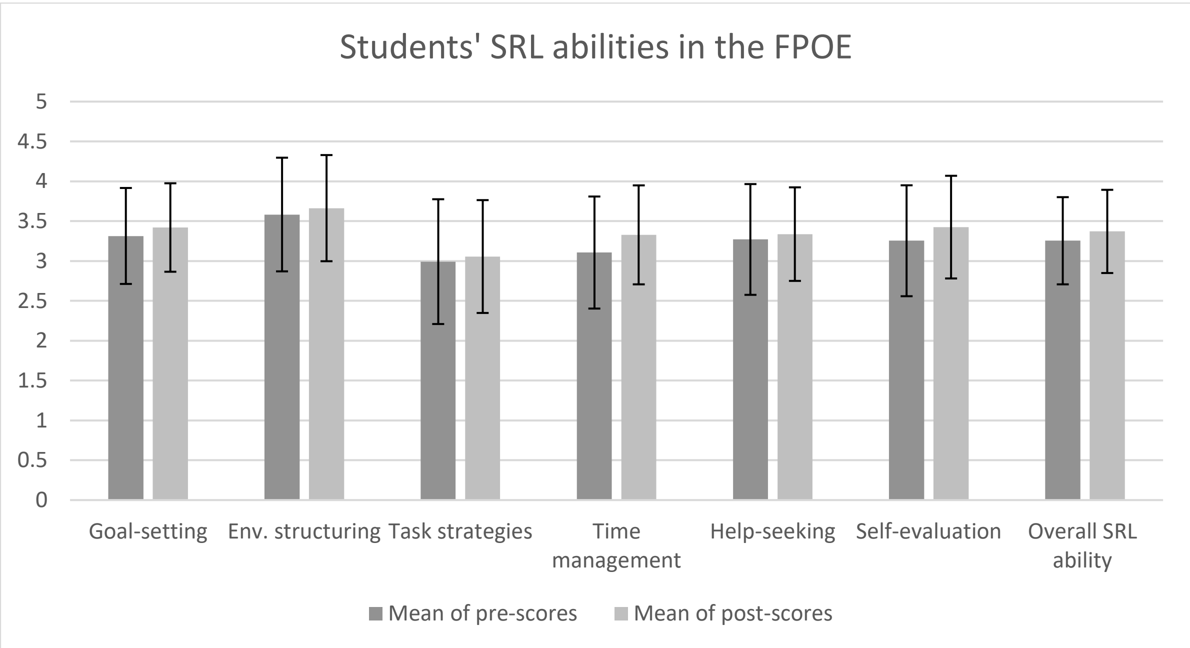

Figure 4.4. Bar chart of the mean scores of each subscale of the SRL abilities and the average SRL ability in the FPOE

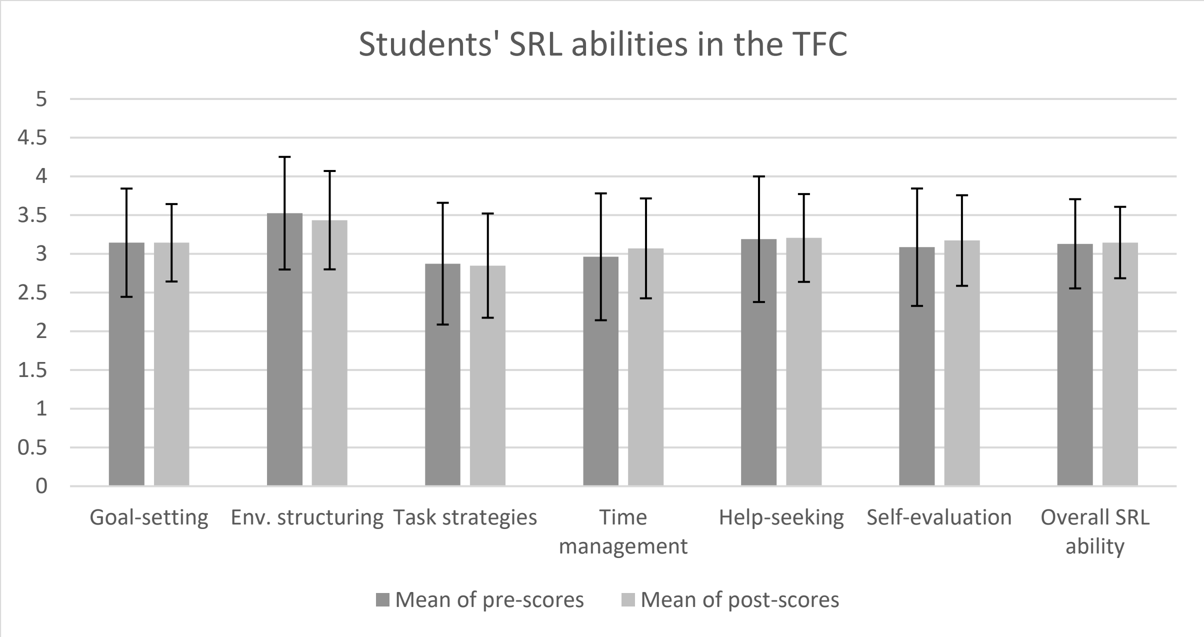

Figure 4.5. Bar chart of the mean scores of each subscale of the SRL abilities and the average SRL ability in the TFC

The results of the paired sample *t*-tests showed that the students' ability of time management significantly was improved following the FPOE intervention, with $t(62) = .2141$, $p = .036 < .05$. However, neither the students' average SRL ability nor its subscales were improved significantly following the TFC intervention. Thus, only the FPOE approach had a positive effect on improving the students' time-management ability.

<u>*Independent sample t-tests of the gain scores on students' SRL abilities by flipped pedagogy*</u>

Independent sample *t*-tests were employed to determine whether there were differences in the gain scores of the students' SRL abilities between different flipped pedagogies. The results are shown in Table 4.4.

According to the results, there was no significant difference in gain scores regarding the students' average SRL ability and its subscales between the FPOE and TFC pedagogies. This finding indicates there was no difference in the improvements in the students' SRL abilities between the two flipped pedagogical approaches.

Table 4.4
Results of independent sample t-tests of gain scores on the students' average SRL ability and its subscales by flipped pedagogy

SRL abilities	*Flipped pedagogy (Independent variable)*	*n*	*M*	*SD*	*t(122)*	*Sig.(2-tailed)*
Goal setting	TFC	61	-.001	.730	-.864 [a]	.389
	FPOE	63	.106	.641		
Environmental structuring	TFC	61	-.089	.938	-1.049 [a]	.296
	FPOE	63	.079	.852		
Task strategies	TFC	61	-.025	.896	-.551 [a]	.583
	FPOE	63	.064	.884		
Time management	TFC	61	.109	.816	-.767 [a]	.445
	FPOE	63	.222	.823		
Help seeking	TFC	61	.016	.765	-.361 [a]	.719
	FPOE	63	.068	.810		
Self-evaluation	TFC	61	.086	.701	-.616 [a]	.539
	FPOE	63	.171	.820		
Average SRL ability	TFC	61	.016	.548	-1.013 [a]	.313
	FPOE	63	.117	.569		

[a] = Equal variances assumed with $p > .05$ for Levene's tests.

4.2.4.2 Learning Achievement (LA)

Paired sample t-tests between the pre- and post-scores of LA in different flipped pedagogies (FPOE and TFC)

A paired sample *t*-test was employed to examine whether the FPOE pedagogical approach made a difference to the students' LA of the FPOE group. Another paired sample *t*-test was employed to examine whether the TFC pedagogical approach made a difference to the students' LA. The results are summarized in Table 4.5.

Table 4.5
Summary of the results for paired sample t-tests on LA at different flipped pedagogies

	Flipped pedagogy											
	FPOE						TFC					
	Posttest		Pretest		*t*	*Sig.*	Posttest		Prettest		*t*	*Sig.*
	M	*SD*	*M*	*SD*		*(2-tailed)*	*M*	*SD*	*M*	*SD*		*(2-tailed)*
LA	46.683	13.171	8.587	3.774	24.748	.000	45.951	11.151	8.557	4.288	25.119	.000

Figure 4.6 shows a bar chart of the mean scores of LA in the FPOE and TFC.

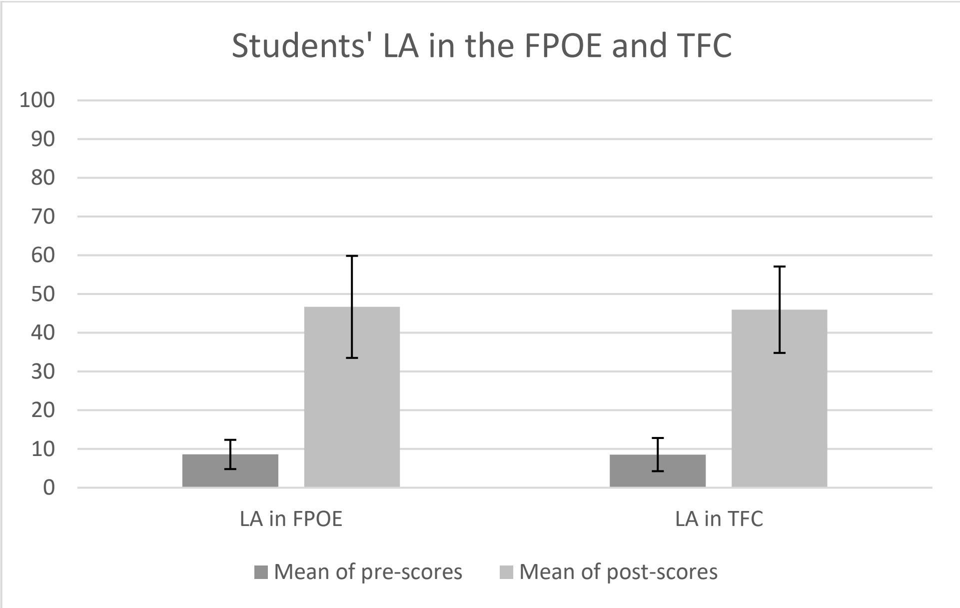

Figure 4.6. Bar chart of the mean scores of LA in the FPOE and TFC

The results of the paired sample *t*-tests showed that the students' LA was significantly improved following the FPOE intervention, with $t(62) = 24.748$, $p < .001$; and their LA was also significantly improved following the TFC intervention, with $t(60) = 25.119$, $p < .001$. Thus, both flipped pedagogies significantly improved the students' LA. On average, the students' LA improved by 38.10 following the FPOE intervention and by 37.39 following the TFC intervention.

Independent sample t-tests of the gain scores in students' LA by flipped pedagogy

An independent sample *t*-test was employed to determine whether there was a difference in the gain scores of the students' LA in different flipped pedagogies. The results are shown in Table 4.6.

Table 4.6
Results for independent sample t-test of gain scores on students' LA by flipped pedagogy

	Flipped pedagogy (Independent variable)	*n*	*M*	*SD*	*t(122)*	*Sig.(2-tailed)*
LA	TFC	61	37.393	11.627	-.327 [a]	.744
	FPOE	63	38.095	12.218		

[a] = Equal variances assumed with $p > .05$ for Levene's tests.

No significant difference was found in the gain scores of the students' LA between the FPOE and TFC approaches. This result indicates no difference regarding the improvements in the students' LA between the two flipped pedagogical approaches.

4.2.4.3 Science Process Skills (SPS)

Paired sample t-tests between the pre- and post-scores of SPS in different flipped pedagogies (FPOE and TFC)

Paired sample *t*-tests were employed to examine whether the FPOE pedagogical approach made a difference to the students' SPS, which consist of subscales of BSPS and ISPS. Paired sample *t*-tests were also employed to examine whether the TFC pedagogical approach made a difference to the students' SPS. The results are summarized in Table 4.7 and Table 4.8.

Table 4.7

Summary of the results for paired sample t-tests of SPS in the FPOE

Measurement	FPOE					
	Posttest		Pretest			
Science Process Skills (SPS)	*M*	*SD*	*M*	*SD*	*t(62)*	*Sig. (2-tailed)*
Observation	4.71	1.142	4.83	1.056	-.680	.499
Communication	4.49	1.378	4.51	1.469	-.077	.939
Classification	4.84	1.096	4.57	1.316	1.563	.123
Measurement	4.44	1.012	3.68	1.189	4.218	.000
Prediction	4.02	1.129	3.71	1.069	1.803	.076
Inference	4.63	1.248	4.51	1.105	.673	.503
Overall BSPS	27.14	4.280	25.81	4.624	2.152	.035
Identifying variables	6.86	2.752	4.75	2.279	6.046	.000
Stating hypotheses	4.54	2.154	3.00	1.769	5.615	.000
Operational defining	2.94	1.655	2.32	1.424	2.703	.009
Designing investigation	1.78	.771	1.30	.835	3.851	.000
Graphing and interpreting data	4.32	1.354	3.38	1.419	4.546	.000
Overall ISPS	20.43	5.721	14.75	5.255	9.806	.000

Table 4.8

Summary of the results for paired sample t-tests of SPS in the TFC

Measurement	TFC					
	Posttest		Pretest			
Science Process Skills (SPS)	*M*	*SD*	*M*	*SD*	*t(60)*	*Sig. (2-tailed)*
Observation	4.85	1.181	5.00	1.017	-.976	.333
Communication	4.34	1.377	4.69	1.104	-1.936	.058
Classification	4.77	1.039	4.95	1.007	-1.144	.257
Measurement	3.98	1.103	3.66	1.078	1.896	.063
Prediction	4.13	1.103	3.95	1.175	1.108	.272
Inference	4.84	1.003	5.00	1.125	-.919	.362
Overall BSPS	26.92	4.428	27.25	3.931	-.575	.568
Identifying variables	6.75	2.560	5.28	2.169	4.259	.000
Stating hypotheses	3.97	1.844	3.70	2.068	1.158	.251
Operational defining	3.08	1.584	2.62	1.714	2.229	.030
Designing investigation	1.80	.703	1.33	.769	3.508	.001
Graphing and interpreting data	3.84	1.344	3.49	1.312	1.814	.075
Overall ISPS	19.44	5.387	16.43	5.798	5.485	.000

Figure 4.7 and Figure 4.8 also display the descriptive statistics of the mean scores of each subscale of the SPS and the overall BSPS and ISPS in the FPOE and the TFC, respectively.

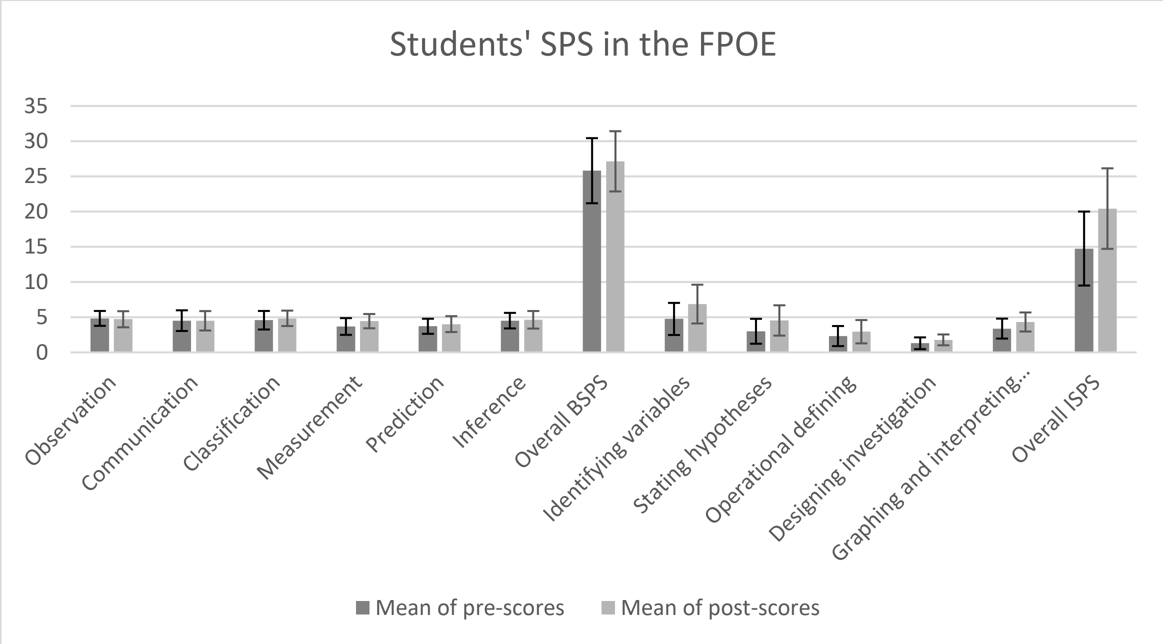

Figure 4.7. Bar chart of the mean scores of each subscale of the SPS and the overall BSPS and ISPS in the FPOE

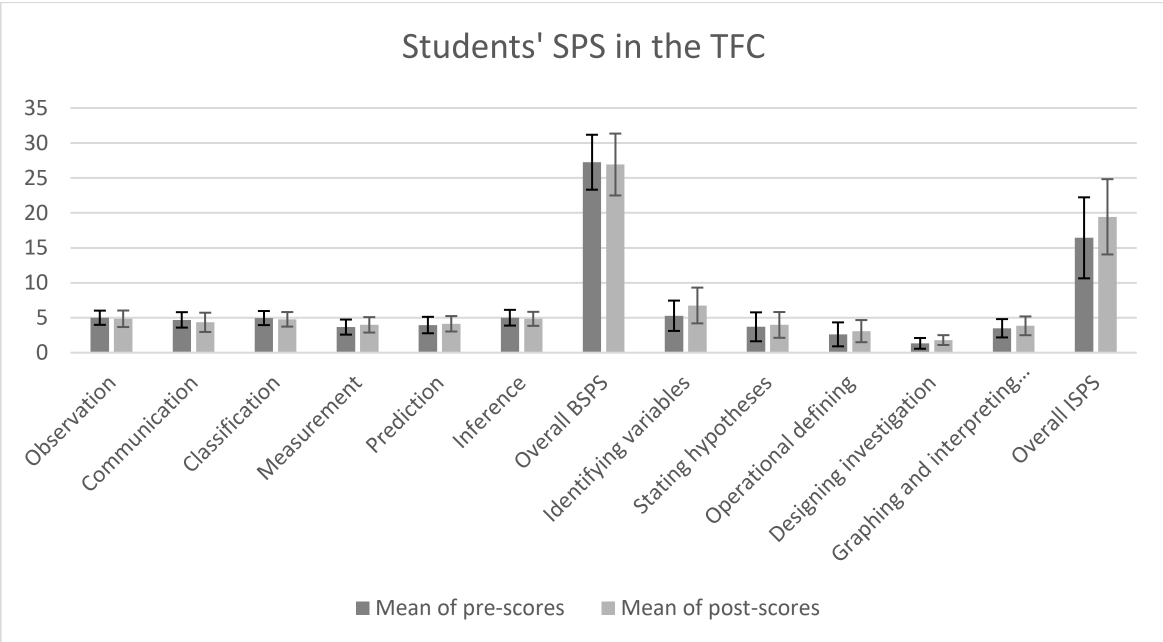

Figure 4.8. Bar chart of the mean scores of each subscale of the SPS and the overall BSPS and ISPS in the TFC

For the FPOE, the results of the paired-samples t-tests showed that the students' overall BSPS was significantly improved, with $t(62) = 2.152$, $p = .035$. On average, the overall BSPS of the students increased by 1.333 following the FPOE intervention. Regarding specific BSPS, the FPOE approach significantly improved the students' measurement skill, with $t(62) = 4.218$, $p < .001$.

Moreover, the overall ISPS was significantly improved following the FPOE intervention, with $t(62) = 9.806$, $p <.001$. On average, the overall ISPS of the students increased by 5.683 following the FPOE intervention. Regarding specific ISPS, the FPOE approach significantly improved all the subscales of ISPS, including the skills of identifying variables, with $t(62) = 6.046$, $p < .001$; stating hypotheses, with $t(62) = 5.615$, $p < .001$; operational defining, with $t(62) = 2.703$, $p = .009$; designing investigation, with $t(62) = 3.851$, $p < .001$, and graphing and interpreting data, with $t(62) = 4.546$, $p < .001$.

For the TFC, the results of the paired-samples *t*-tests showed neither the students' overall BSPS nor its subscales were improved significantly following the TFC intervention.

In addition, the overall ISPS was significantly improved following the TFC intervention, with $t(60) = 5.485$, $p <.001$. On average, the overall ISPS of the students increased by 3.016 following the FPOE intervention. Regarding specific ISPS, the TFC approach significantly improved the skills of identifying variables, with $t(60) = 4.259$, $p < .001$; operational defining, with $t(60) = 2.229$, $p = .030$; designing investigation, with $t(60) = 3.508$, $p = .001 < .05$.

Independent sample t-tests of the gain scores of the students' SPS by flipped pedagogy

Independent sample *t*-tests were employed to determine whether there were differences in the gain scores of the students' SPS and subscales between the different flipped pedagogies. The results are in Table 4.9.

Table 4.9

Results for independent sample t-tests of students' gain scores of SPS by flipped pedagogy

Post-Science Process Skills (SPS)	*Flipped pedagogy (Independent variable)*	*n*	*M*	*SD*	*t(122)* [a]	*Sig. (2-tailed)*
Observation	TFC	61	-.146	1.181	-.163 [a]	.870
	FPOE	63	-.111	1.297		
Communication	TFC	61	-.344	1.389	-1.201 [a]	.232
	FPOE	63	-.016	1.641		
Classification	TFC	61	-.180	1.232	-1.922 [a]	.057
	FPOE	63	.270	1.370		
Measurement	TFC	61	.328	1.351	-1.734 [a]	.085
	FPOE	63	.762	1.434		
Prediction	TFC	61	.180	1.272	-.519 [a]	.605
	FPOE	63	.302	1.328		
Inference	TFC	61	-.164	1.393	-1.119 [a]	.265
	FPOE	63	.127	1.497		
Overall BSPS	TFC	61	-.328	4.456	-1.969 [a]	.051
	FPOE	63	1.333	4.919		
Identifying variables	TFC	61	1.475	2.706	-1.292 [a]	.199
	FPOE	63	2.111	2.771		
Stating hypotheses	TFC	61	.262	1.769	-3.580 [a]	.000
	FPOE	63	1.540	2.176		
Operational defining	TFC	61	.459	1.608	-.519 [a]	.605
	FPOE	63	.619	1.818		
Designing investigation	TFC	61	.475	1.058	-.004 [a]	.997
	FPOE	63	.476	.981		
Graphing and interpreting data	TFC	61	.344	1.482	-.2111 [a]	.037
	FPOE	63	.937	1.635		
Overall ISPS	TFC	61	3.016	4.295	-3.334 [a]	.001
	FPOE	63	5.683	4.600		

[a] = Equal variances assumed with $p > .05$ for Levene's tests.
[b] = Equal variances not assumed with $p < .05$ for Levene's tests.

According to the results, there was a marginally significant difference of gain scores for the students' overall BSPS between the FPOE and TFC pedagogies. On average, the improvement of the students' overall BSPS ($M = 1.333$, $SD = 4.969$) in the FPOE approach was significantly higher than that ($M = -.328$, $SD = 4.456$) in the TFC, with $t(122) = -1.969$, $p = .051$. Regarding BSPS subscales, there was no significant difference in gain scores between the FPOE and TFC pedagogies.

For the ISPS, the results showed that there was a significant difference in the gain scores of the students' overall ISPS, with $t(122) = -3.334$, $p = .001$. On average, the improvement of the students' overall ISPS ($M = 5.683$, $SD = 4.600$) in the FPOE approach was significantly higher than that ($M = 3.016$, $SD = 4.295$) in the TFC approach, with $t(122) = -3.334$, $p = .001$. Regarding ISPS subscales, the improvement of the students' stating hypotheses skill ($M = 1.540$, $SD = 2.176$) in the FPOE approach was significantly higher than that ($M = .262$, $SD = 1.769$) in the TFC approach, with $t(122) = -3.580$, $p < .001$. The improvement of the students' graphing and interpreting data skill ($M = .937$, $SD = 1.635$) in the FPOE approach was also significantly higher than that ($M = .344$, $SD = 1.482$) in the TFC approach, with $t(122) = -.2111$, $p = .037$.

4.2.4 Statistical Analysis Addressing the Second Research Question (RQ2)

To address the second research question (RQ2), which focuses on all pedagogical approaches, an ANOVA of the overall post-test scores and a MANOVA of the subscales of post-test scores were conducted. The following sections outline the statistical findings. Table 4.10 shows the descriptive statistics of the quantitative data collected for addressing RQ2.

Table 4.10
Descriptive statistics of the quantitative data collected to address RQ2

	Pedagogy							
Measurement	TC (n = 63)#		TFC (n =61)		FPOE (n = 63)		All (n =187)	
Post-scores	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Goal setting	3.171	.637	3.143	.501	3.420	.555	3.246	.578
Environmental structuring	3.571	.718	3.435	.635	3.663	.666	3.558	.677
Task strategies	2.762	.763	2.848	.673	3.056	.708	2.889	.723
Time management	3.000	.665	3.071	.645	3.328	.621	3.134	.656
Help seeking	3.123	.630	3.205	.567	3.337	.587	3.222	.599
Self-evaluation	3.191	.627	3.172	.585	3.425	.644	3.263	.627
Average SRL ability	3.138	.548	3.146	.461	3.371	.521	3.219	.521
LA	40.814	13.827	45.951	11.151	46.683	13.171	44.546	12.953
Observation	4.70	1.131	4.85	1.181	4.71	1.142	4.75	1.147
Communication	4.52	1.255	4.34	1.377	4.49	1.378	4.45	1.333
Classification	4.76	.946	4.77	1.039	4.84	1.096	4.79	1.024
Measurement	3.86	1.255	3.98	1.103	4.44	1.012	4.10	1.151
Prediction	3.73	1.035	4.13	1.103	4.02	1.129	3.96	1.097
Inference	4.63	1.235	4.84	1.003	4.63	1.248	4.70	1.167
Overall BSPS	26.21	4.190	26.92	4.428	27.14	4.280	26.75	4.295
Identifying variables	5.90	2.668	6.75	2.560	6.86	2.752	6.50	2.683
Stating hypotheses	4.02	1.727	3.97	1.844	4.54	2.154	4.18	1.925
Operational defining	2.92	1.619	3.08	1.584	2.94	1.655	2.98	1.613
Designing investigation	1.73	.677	1.80	.703	1.78	.771	1.77	.715
Graphing and interpreting data	4.10	1.254	3.84	1.344	4.32	1.354	4.09	1.325
Overall ISPS	18.67	5.349	19.44	5.387	20.43	5.721	19.51	5.508

= for LA, n =59.

4.2.5.1 Self-Regulated Learning (SRL) Abilities

One-way between-subjects ANOVA of the students' post-scores of average SRL ability and a MANOVA of the students' post-scores of SRL subscales by pedagogy

To investigate further whether the FPOE pedagogical approach was the most effective at improving the students' SRL abilities when compared with the TFC (control) and the TC (historical control) approaches, a one-way between-subjects ANOVA of the students' post-scores of the average SRL ability was conducted. Moreover, a MANOVA of the students' post-scores of the SRL subscales was carried out to investigate whether there was an effect of pedagogy on the linear combination of the subscale variables of the SRL abilities. Figure 4.9 shows a bar chart of the students' mean post-scores of the average SRL ability and its subscales in the three pedagogies.

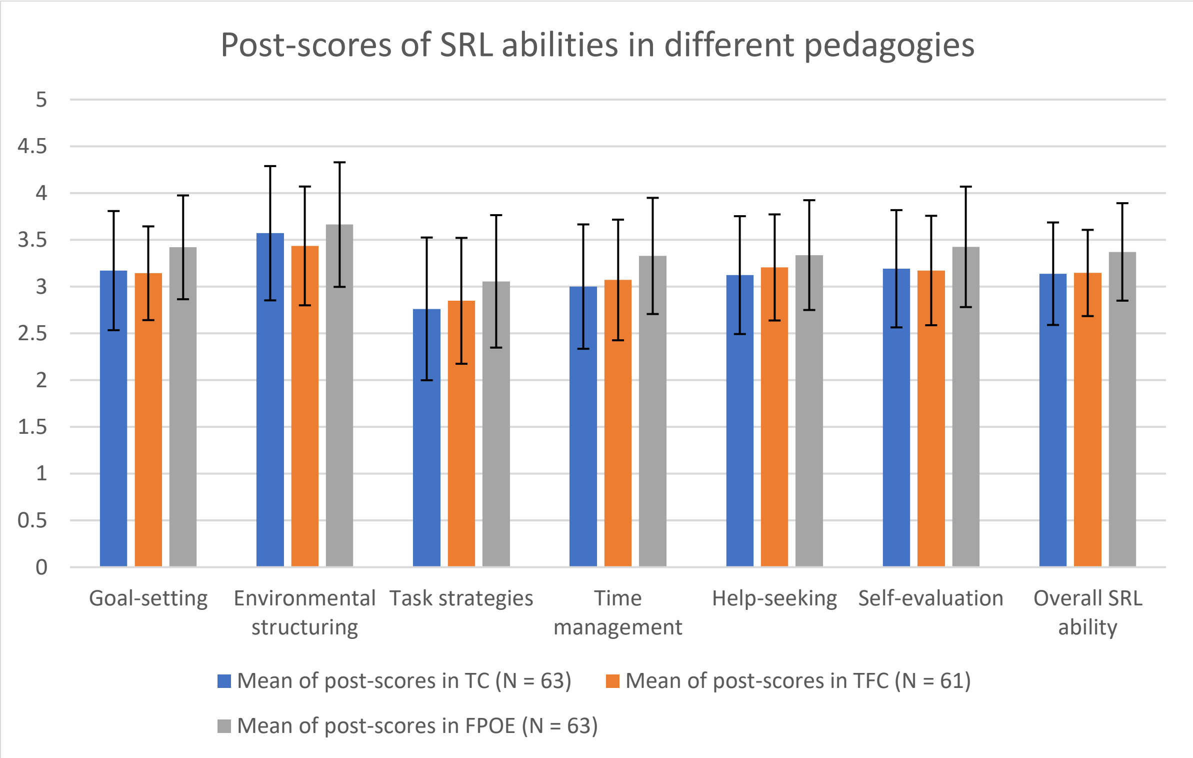

Figure 4.9. Bar chart of the mean post-scores of each subscale of the SRL abilities and the average SRL ability in all pedagogies

For the ANOVA, the assumption of homogeneity of variance was met prior to the test, with a non-significant result for Levene's test, $F(2,184) = 1.06$, $p = .349$. Without violating the assumption of the test, the ANOVA was conducted. Table 4.11 shows the result of the ANOVA of the average SRL ability.

Table 4.11
Result of the one-way ANOVA of the average students' post SRL ability by pedagogy

		Sum of Squares	*df*	*Mean Square*	*F*	*Sig.*
Average SRL ability	Between Groups	2.199	2	1.100	4.196	.017
	Within Groups	48.225	184	.262		
	Total	50.424	186			

The ANOVA result for the average SRL ability was significant, $F(2,184) = 4.196$, $p = .017$, with nearly a medium effect size $\eta^2 = 2.199/50.424 = .044$, suggesting that the effectiveness of the three pedagogical approaches on the students' SRL abilities following the interventions were different.

Post hoc comparisons with a Bonferroni adjustment were used to make pairwise comparisons of the means of the average SRL ability of the three approaches, and the results are illustrated in Table 4.12.

Table 4.12
Post hoc Bonferroni (with adjustment) comparison for the average SRL ability by pedagogy (displaying significant results between flipped approaches with TC only)

Measurement	*Comparisons*	*Mean Difference*	*Std. Error*	*Sig.*	*95% CI*	
					Lower Bound	*Upper Bound*
Average SRL ability	FPOE vs. TC	.233	.091	.034	.013	.454

The result showed that the students' average SRL ability mean score (M= 3.371, SD= .521) in the FPOE approach was significantly higher than that (M= 3.138, SD= .548) in the TC approach (p = .034).

For the MANOVA of the subscales of the SRL abilities, the test of the assumption of homogeneity of covariance was carried out using Box's test of equality of covariance matrices, with $p < .001$ as a criterion. The result showed that there were no significant differences between the covariance matrices, with Box's M (75.892) = .002. Therefore, the assumption of homogeneity of covariance was not violated and the MANOVA was conducted.

Table 4.13 shows the result of the MANOVA. Using Wilks' lambda (λ), the effect of pedagogy on the linear combination of the subscales of the students' SRL abilities was not significant, with Wilks' $\lambda = .918$, $F(12, 358) = 1.305$, $p = .213$. Thus, there were no significant differences of the linear combination of SRL subscales between the pedagogies.

Table 4.13
Result of the MANOVA on the subscales of the SRL abilities by pedagogy

	Value	*F*	Hypothesis df	Error df	*Sig.*	Partial Eta Squared
Pillai's trace	.084	1.308	12.000	360.000	.211	.042
Wilks' lambda	.918	1.305[a]	12.000	358.000	.213	.042
Hotelling's trace	.088	1.302	12.000	356.000	.215	.042
Roy's largest root	.061	1.836[b]	6.000	180.000	.094	.058

Each F tests the multivariate effect of Pedagogy. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.
a. = Exact statistic
b. = The statistic is an upper bound on F that yields a lower bound on the significance level.

Despite the non-significant result of the MANOVA, it was important to explore further the effect of pedagogies on the SRL subscales independently, since a significant result was obtained by the ANOVA regarding average SRL ability. Therefore, one-way between-subjects ANOVAs on the subscales of the students' post-SRL abilities were carried out independently. The results are shown in Table 4.14.

With reference to Table 4.14, the results of the ANOVAs showed that the students' goal-setting ($F(2,184) = 4.496$, $p = .012$), time management ($F(2,184) = 4.505$, $p = .012$), and self-evaluation abilities ($F(2,184) = 3.232$, $p = .042$) were significantly different among the three pedagogical approaches.

Table 4.14
Summary of one-way ANOVAs for students' post-score of SRL subscales by pedagogy

		Sum of Squares	*df*	*Mean Square*	*F*	*Sig.*
Goalsetting	Between Groups	2.898	2	1.449	4.496	.012
	Within Groups	59.299	184	.322		
	Total	62.197	186			
Environmental structuring	Between Groups	1.621	2	.811	1.783	.171
	Within Groups	83.645	184	.455		
	Total	85.266	186			
Task strategies	Between Groups	2.866	2	1.433	2.797	.064
	Within Groups	94.269	184	.512		
	Total	97.135	186			
Time management	Between Groups	3.732	2	1.866	4.505	.012
	Within Groups	76.226	184	.414		
	Total	79.958	186			
Help seeking	Between Groups	1.473	2	.736	2.074	.129
	Within Groups	65.317	184	.355		
	Total	66.790	186			
Self-evaluation	Between Groups	2.480	2	1.240	3.232	.042
	Within Groups	70.611	184	.384		
	Total	73.092	186			

Post hoc comparisons with a Bonferroni adjustment were used to make pairwise comparisons of the means of the post-scores of the SRL subscales in the three approaches, and the results are shown in Table 4.15. Since a comparison between the FPOE and the TFC was made with more statistical power in the previous section (Section 4.2.3), the results only focus on the significant differences between the flipped approaches and the TC.

Table 4.15
Post hoc Bonferroni comparison for the SRL subscales by pedagogy (displaying significant results between flipped approaches with TC only)

SRL abilities	*Comparisons*	*Mean Difference*	*Std. Error*	*Sig.*	*95% CI* Lower Bound	*95% CI* Upper Bound
Goal setting	FPOE vs. TC	.248	.101	.045	.004	.493
Time management	FPOE vs TC	.327	.115	.014	.050	.604

The results showed that the mean score (*M* = 3.420, *SD* = .555) of the students' goal-setting ability in the FPOE approach was significantly higher than that (*M* = 3.171, *SD* = .637) in the TC approach (*p* = .045). The mean score (*M* = 3.328, *SD* = .621) of the students' time-management ability in the FPOE approach was also significantly higher than that (*M* = 3.000, *SD* = .665) in the TC approach (*p* = .014).

4.2.5.2 Learning Achievement (LA)

One-way between-subjects ANOVA of the students' post-scores of overall LA by pedagogy

To investigate whether the FPOE pedagogical approach was the most effective to improve students' LA compared with the TFC (control) and the TC (historical control) approaches, a one-way between-subjects ANOVA of the students' LA post-scores was carried out. Figure 4.10 shows a bar chart of the students' mean LA post-scores in the three pedagogies.

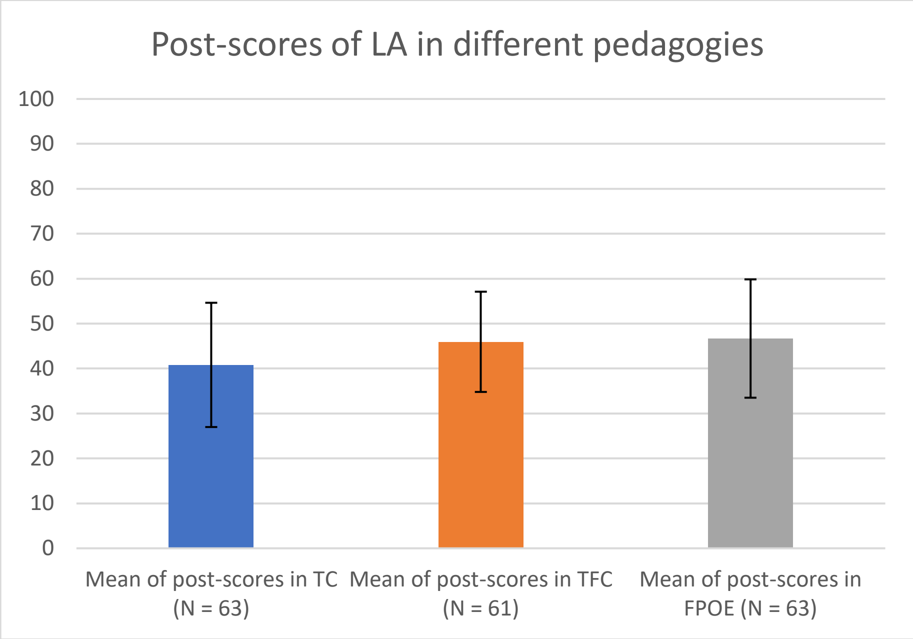

Figure 4.10. Bar chart of the mean LA post-scores in all pedagogies

For the ANOVA, the assumption of homogeneity of variance was met prior to the test, with a non-significant result of the Levene's test, $F(2,180) = 1.158$, $p = .317$. Without violating the assumption of the test, the ANOVA was conducted. Table 4.16 shows the result of the ANOVA of the LA by pedagogy.

Table 4.16
Result of the one-way ANOVA of students' post-scores of LA by pedagogy

		Sum of Squares	*df*	*Mean Square*	*F*	*Sig.*
Post-LA	Between Groups	1229.903	2	614.951	3.777	.025
	Within Groups	29305.452	180	162.808		
	Total	30535.355	182			

The ANOVA result for the LA was significant, $F(2,180) = 3.777$, $p = .025$, with nearly a medium effect size $\eta^2 = 1229.9/30535.4 = .04$, suggesting that there were differences regarding the effectiveness of the pedagogical approaches on students' LA post-scores.

Post hoc comparisons with a Bonferroni adjustment were used to make pairwise comparisons of the means of the three approaches, and the results are illustrated in Table 4.17.

Table 4.17
Post hoc Bonferroni (with adjustment) comparison for the post-scores of LA by pedagogy

					95% CI	
(I) pedagogy	*(J) Pedagogy*	*Mean Difference (I-J)*	*Std. Error*	*Sig.*	*Lower Bound*	*Upper Bound*
TC	TFC	-5.137	2.323	.086	-10.768	.493
	FPOE	-5.869	2.312	.036	-11.455	-.283
TFC	TC	5.137	2.330	.086	-.493	10.768
	FPOE	-.732	2.292	1.000	-6.271	4.807
FPOE	TC	5.869	2.312	.036	.283	11.455
	TFC	7.317	2.292	1.000	-4.807	6.271

The results showed that the mean score (M = 46.683, SD = 13.171) of the students' LA in the FPOE approach was significantly higher than that (M = 40.814, SD = 13.827) in the TC approach (p = .036).

4.2.5.3 Science Process Skills (SPS)

One-way between-subjects ANOVAs of the students' post-scores of overall BSPS and ISPS, and MANOVAs of the students' post-scores of BSPS and ISPS subscales by pedagogy

To investigate whether the FPOE approach was the most effective at improving the students' SPS compared with the TFC (control) and the TC (historical control) approaches, one-way between-subjects ANOVAs of the students' post-scores of the overall BSPS and ISPS were conducted. Moreover, two one-way between-subjects MANOVAs of the students' post-scores of the BSPS and ISPS subscales were carried out to investigate whether there was any effect of pedagogy on the linear combination of the subscale variables of the BSPS and ISPS. Bar charts of the students' mean post-scores of the BSPS and ISPS and their subscales in the three pedagogies are provided in Figure 4.11 and Figure 4.12, respectively.

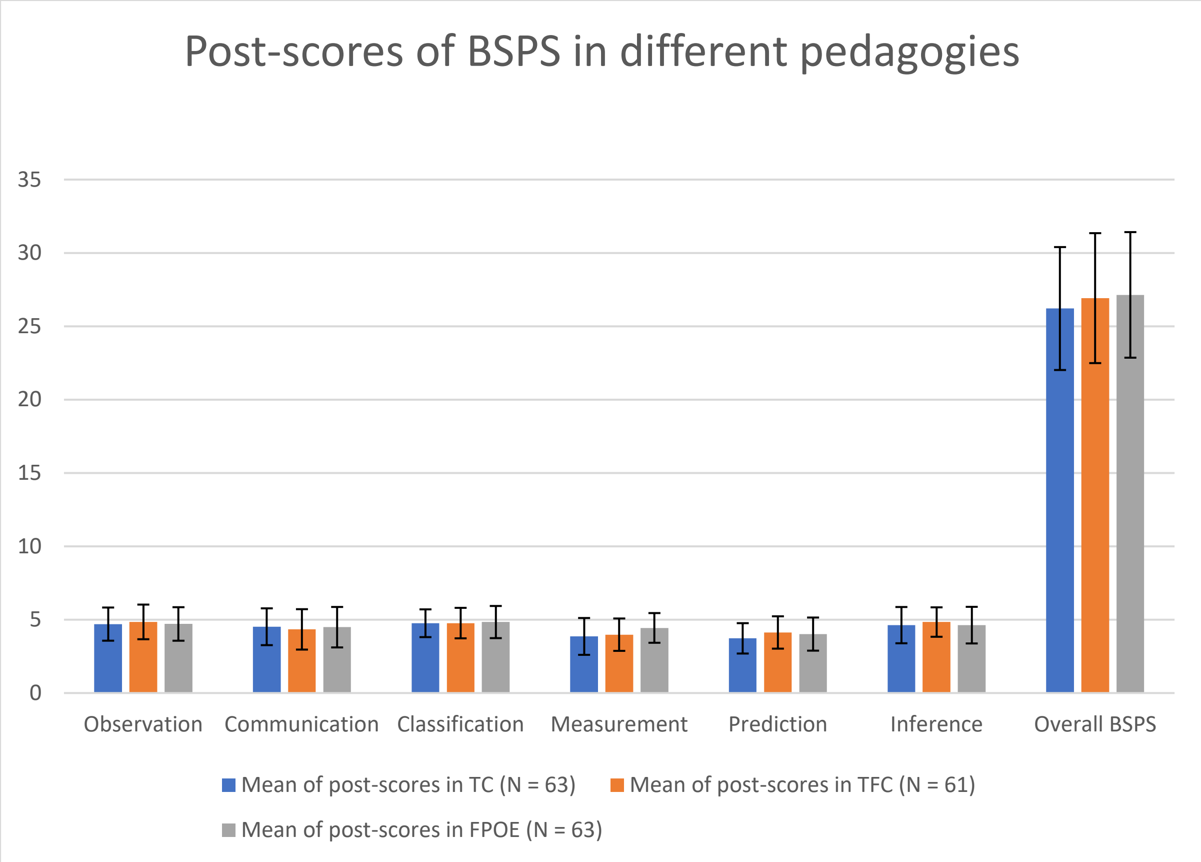

Figure 4.11. Bar chart of the mean post-scores of each subscale of the BSPS and the overall BSPS in all pedagogies

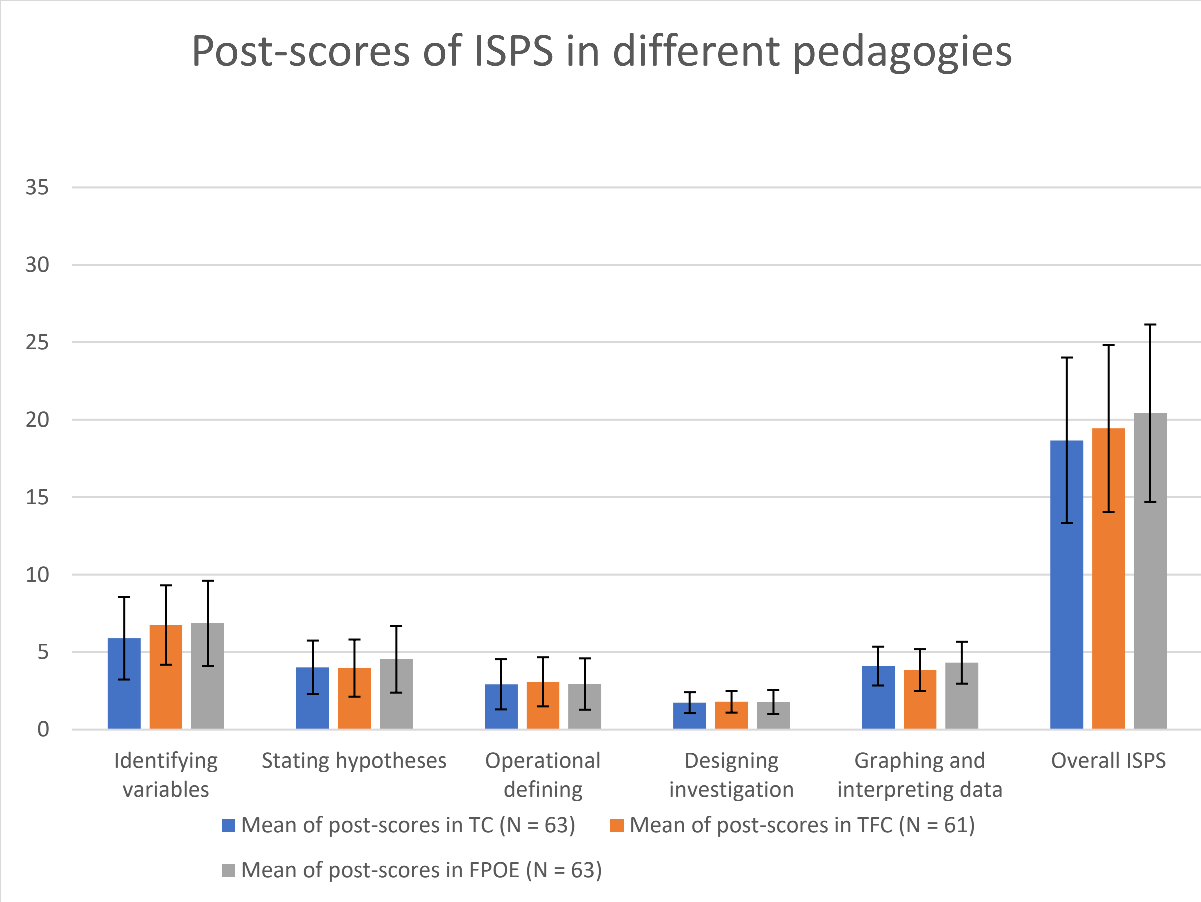

Figure 4.12. Bar chart of the mean post-scores of each subscale of the ISPS and the overall ISPS in all pedagogies

For the ANOVAs of the overall BSPS and ISPS, the assumption of homogeneity of variance was met prior to the test, with non-significant results for the Levene's tests, $F(2,184) = 0.67$, $p = 0.935$ for BSPS, and $F(2,184) = 0.031$, $p = 0.969$ for ISPS. Without violating the assumption of the tests, the ANOVAs were conducted. Table 4.18 shows the results of the ANOVAs of the overall BSPS and ISPS.

Table 4.18
Results of the one-way ANOVAs of the post-scores of the overall BSPS and ISPS by pedagogy

		Sum of Squares	*df*	*Mean Square*	*F*	*Sig.*
Overall Basic Science Process skills (BSPS)	Between Groups	30.063	2	15.031	.813	.445
	Within Groups	3400.622	184	18.482		
	Total	3430.684	186			
Overall Integrated Science Process Skills (ISPS)	Between Groups	98.239	2	49.119	1.630	.199
	Within Groups	5544.478	184	30.133		
	Total	5642.717	186			

The ANOVA result of the overall BSPS was not significant, $F(2,184) = .813$, $p = .445$, suggesting there was no significant difference of the students' overall BSPS among the three pedagogical approaches. The ANOVA result of the overall ISPS was not significant either, $F(2,184) = 1.63$, $p = .199$, suggesting there was no significant difference of the students' overall ISPS among the three pedagogical approaches.

For the MANOVA of the subscales of the BSPS, the test of the assumption of homogeneity of covariance was conducted using Box's test of equality of covariance matrices, with $p < .001$ as a criterion. The result showed that there were no significant differences between the covariance matrices, with Box's M (41.471) =.579. Thus, the assumption of homogeneity of covariance was not violated and the MANOVA was conducted.

Table 4.19 shows the result of the MANOVA of the subscales of BSPS. Using Wilks' lambda (λ), the effect of pedagogy on the linear combination of the subscales of the students' BSPS was not significant, with Wilks' $\lambda = .903$, $F(12, 358) = 1.570$, $p = .098$.

Table 4.19
Result of the MANOVA of the subscales of the BSPS by pedagogy

	Value	*F*	Hypothesis df	Error df	*Sig.*	Partial Eta Squared
Pillai's trace	.100	1.575	12.000	360.000	.097	.050
Wilks' lambda	.903	1.570[a]	12.000	358.000	.098	.050
Hotelling's trace	.105	1.564	12.000	356.000	.100	.050
Roy's largest root	.068	2.034[b]	6.000	180.000	.063	.063

a.= Exact statistic
b.= The statistic is an upper bound on F that yields a lower bound on the significance level.

For the MANOVA of the subscales of the ISPS, the test of the assumption of homogeneity of covariance was conducted using Box's test of equality of covariance matrices, with $p < .001$ as a criterion. The result showed that there were no significant differences between the covariance matrices, with Box's M (41.471) =.579. Thus, the assumption homogeneity of covariance was not violated and the MANOVA was conducted.

Table 4.20 shows the result of the MANOVA of the subscales of ISPS. Using Wilks' lambda (λ), the effect of pedagogy on the linear combination of the subscales of the students' ISPS was not significant, with Wilks' $\lambda = .931$, $F(10, 360) = 1.313$, $p = .222$.

Table 4.20
Results of the MANOVA of the subscales of the ISPS by pedagogy

	Value	*F*	Hypothesis df	Error df	*Sig.*	Partial Eta Squared
Pillai's trace	.070	1.319	10.000	362.000	.218	.035
Wilks' lambda	.931	1.313[a]	10.000	360.000	.222	.035
Hotelling's trace	.073	1.307	10.000	358.000	.225	.035
Roy's largest root	.044	1.580[b]	5.000	181.000	.168	.042

a. = Exact statistic
b. = The statistic is an upper bound on F that yields a lower bound on the significance level.

Overall, the findings showed that there was no significant difference of the linear combination of BSPS subscales between the pedagogies, nor there was no significant difference of the linear combination of ISPS subscales between the pedagogies.

4.2.5 Statistical Analysis Addressing the Third Research Question (RQ3)

To address the third research question (RQ3), independent sample *t*-tests of the gain scores and two-way between-subjects ANOVAs/MANOVAs of the students' gain scores were conducted. Table 4.21 and Table 4.22 show the descriptive statistics of the quantitative data collected for addressing RQ3.

Table 4.21
Descriptive statistics of the quantitative data collected in the FPOE to address RQ2

Measurement	Learning ability											
	Lower (n = 31)						Higher (n = 32)					
SRL abilities	Posttest		Pretest		Gain scores (post - pre)		Posttest		Pretest		Gain scores (post - pre)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Goal setting	3.219	.367	3.207	.553	.013	.527	3.614	.637	3.419	.637	.196	.731
Env. structuring	3.484	.595	3.532	.580	-.048	.848	3.836	.694	3.633	.828	.203	.851
Task strategies	2.863	.642	2.895	.676	-.032	.839	3.242	.728	3.086	.874	.156	.931
Time management	3.139	.485	3.043	.698	.097	.668	3.510	.688	3.167	.714	.344	.945
Help seeking	3.210	.540	3.250	.487	-.040	.824	3.461	.613	3.289	.857	.172	.794
Self-evaluation	3.202	.522	3.169	.572	.032	.808	3.641	.683	3.336	.800	.305	.822
Average SRL	3.186	.362	3.183	.406	.004	.472	3.550	.593	3.322	.654	.228	.637
LA	41.419	10.223	7.613	3.263	33.807	10.445	51.781	13.830	9.531	4.040	42.250	12.521
Observation	4.35	1.253	4.71	1.131	-.355	1.380	5.06	.914	4.94	.982	.125	1.185
Communication	4.16	1.416	4.35	1.684	-.194	1.447	4.81	1.281	4.66	1.234	.156	1.816
Classification	4.68	1.194	4.55	1.546	.129	1.432	5.00	.984	4.59	1.073	.406	1.316
Measurement	4.29	1.071	3.77	1.257	.516	1.546	4.59	.946	3.59	1.132	1.000	1.295
Prediction	3.87	1.204	3.48	1.092	.387	1.308	4.16	1.051	3.94	1.014	.2188	1.362
Inference	4.65	1.305	4.19	1.195	.452	1.502	4.63	1.212	4.81	.931	-.188	1.447
Overall BSPS	26.00	4.879	25.06	5.639	.9355	5.459	28.25	3.321	26.53	3.302	1.719	4.386
Identifying variables	6.00	2.477	3.97	1.703	2.032	2.442	7.69	2.788	5.50	2.527	2.188	3.095
Stating hypotheses	3.16	1.655	2.58	1.689	.581	2.248	5.88	1.699	3.41	1.775	2.469	1.665
Operation defining	2.48	1.435	1.90	1.221	.581	1.689	3.38	1.755	2.72	1.508	.656	1.961
Designing investigation	1.61	.844	1.10	.831	.516	1.092	1.94	.669	1.50	.803	.438	.878
Graphing and interpreting data	3.87	1.455	2.74	1.365	1.129	1.803	4.75	1.107	4.00	1.191	.750	1.459
Overall ISPS	17.13	4.233	12.29	4.599	4.839	4.465	23.63	5.167	17.13	4.784	6.500	4.649

Table 4.22

Descriptive statistics of the quantitative data collected in the TFC to address RQ2

Measurement	Learning ability											
	Lower (*n* = 30)						Higher (*n* = 31)					
SRL abilities	Posttest		Pretest		Gain scores (post - pre)		Posttest		Pretest		Gain scores (post - pre)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Goal setting	3.078	.496	3.153	.841	-.075	.806	3.207	.505	3.136	.540	.071	.654
Env. structuring	3.193	.574	3.542	.876	-.348	1.030	3.669	.610	3.508	.561	.161	.776
Task strategies	2.833	.708	2.800	.834	.033	.916	2.863	.648	2.944	.744	-.081	.888
Time management	3.089	.661	2.866	.916	.223	.904	3.053	.639	3.054	.715	-.001	.720
Help seeking	3.117	.516	3.025	.844	.092	.684	3.290	.609	3.347	.757	-.057	.841
Self-evaluation	3.183	.640	2.933	.853	.250	.785	3.161	.538	3.234	.632	-.073	.578
Average SRL	3.082	.485	3.053	.643	.029	.588	3.207	.435	3.205	.502	.002	.517
LA	40.967	8.491	7.500	4.108	33.467	9.313	50.774	11.407	9.581	4.272	41.194	12.496
Observation	4.60	1.276	4.90	1.094	-.300	.837	5.10	1.044	5.10	.944	.000	1.438
Communication	4.30	1.264	4.50	1.196	-.200	1.064	4.39	1.498	4.87	.991	-.484	1.651
Classification	4.67	.922	4.87	1.074	-.200	.961	4.87	1.147	5.03	.948	-.161	1.463
Measurement	3.80	1.186	3.47	1.106	.333	1.348	4.16	1.003	3.84	1.036	.323	1.376
Prediction	4.27	1.202	3.97	1.189	.300	1.179	4.00	1.000	3.94	1.181	.065	1.365
Inference	5.03	.809	4.93	1.172	.100	1.269	4.65	1.142	5.06	1.093	-.419	1.478
Overall BSPS	26.67	4.444	26.63	4.537	.033	3.548	27.16	4.473	27.84	3.205	-.677	5.224
Identifying variables	5.97	2.385	4.50	2.013	1.467	2.921	7.52	2.528	6.03	2.073	1.484	2.528
Stating hypotheses	3.13	1.167	3.13	1.676	.000	1.554	4.77	2.028	4.26	2.280	.5161	1.947
Operation defining	2.63	1.450	2.20	1.495	.4333	1.547	3.52	1.610	3.03	1.835	.484	1.691
Designing investigation	1.93	.740	1.17	.592	.767	1.040	1.68	.653	1.48	.890	.194	1.014
Graphing and interpreting data	3.47	1.306	3.10	1.185	.367	1.608	4.19	1.302	3.87	1.335	.323	1.376
Overall ISPS	17.13	4.577	14.10	4.428	3.033	4.745	21.68	5.224	18.68	6.134	3.000	3.890

4.2.6.1 Self-Regulated Learning (SRL) Abilities

Independent sample t-tests of the gain scores of the students' SRL abilities by learning ability in different flipped pedagogies (FPOE and TFC)

Independent sample *t*-tests were employed to determine whether there were differences in the gain scores of SRL abilities between students with different learning abilities in different flipped pedagogies. The results are summarized in Table 4.23 and Table 4.24.

Table 4.23

Summary of the results for the independent samples t-tests of the gain scores of SRL abilities by learning ability in the FPOE

Measurement	Gain scores (posttest-pretest)					
SRL abilities	Higher learning ability (n = 32)		Lower learning ability (n = 31)			
	M	*M*	*M*	*SD*	*t*	*Sig. (2-tailed)*
Goal setting	.196	.196	.013	.527	1.137 [a]	.260
Env. structuring	.203	.203	-.048	.848	1.175 [a]	.244
Task strategies	.156	.156	-.032	.839	.844 [a]	.402
Time management	.344	.344	.097	.668	1.203 [b]	.234
Help seeking	.172	.172	-.040	.824	1.041 [a]	.302
Self-evaluation	.305	.305	.032	.808	1.326 [a]	.190
Average SRL ability	.228	.228	.004	.472	1.581 [a]	.119

[a] = Equal variances assumed with p > .05 for Levene’s tests.
[b] = Equal variances not assumed with p < .05 for Levene’s tests.

The results in Table 4.23 showed no significant difference of gain scores of SRL abilities among the students with different learning abilities in the FPOE approach.

Thus, the improvements in the students’ SRL abilities were not significantly different according to different learning ability in the FPOE pedagogical approach.

Table 4.24

Summary of the results for independent sample t-tests of the gain scores of SRL abilities by learning ability in the TFC

Measurement	Gain scores (posttest-pretest)					
SRL abilities	Higher learning ability (n = 31)		Lower learning ability (n = 30)			
	M	*M*	*M*	*SD*	*t*	*Sig. (2-tailed)*
Goal setting	.071	.071	-.075	.806	.780 [a]	.439
Env. structuring	.161	.161	-.348	1.030	2.188 [a]	.033
Task strategies	-.081	-.081	.033	.916	-.493 [a]	.624
Time management	-.001	-.001	.223	.904	-1.069 [a]	.289
Help seeking	-.057	-.057	.092	.684	-.753 [a]	.454
Self-evaluation	-.073	-.073	.250	.785	-1.823 [b]	.074
Average SRL ability	.002	.002	.029	.588	-.191 [a]	.849

[a] = Equal variances assumed with p > .05 for Levene’s tests.
[b] = Equal variances not assumed with p < .05 for Levene’s tests.

In Table 4.24, significant result from the *t*-tests of the gain scores among students with different learning abilities were obtained regarding the environmental structuring ability in the TFC approach, with $t(59) = 2.188$, $p = .033$ (two-tailed). On average, the improvement of environmental structuring ability of the students with higher learning ability (HL) ($M = .161$, $SD = .776$) was significantly higher than that of students with lower learning ability (LL) ($M = -.348$, $SD = 1.030$), with $t(59) = 2.188$, $p = .033$ in the TFC approach.

Two-way between-subjects ANOVA of students' post-scores of average SRL ability and MANOVA of students' post-scores of SRL subscales by flipped pedagogy and learning ability

A two-way between-subjects ANOVA of the students' gain scores of average SRL ability was conducted to investigate whether there was an interaction effect between flipped pedagogy and learning ability. For the ANOVA, the assumption of homogeneity of variance was met prior to the test, with a non-significant result of Levene's test, $F(3,120) = .877$, $p = .455$. Without violating the assumption of the test, the ANOVA was conducted. Table 4.25 shows the results of the two-way ANOVA on the average SRL ability.

Table 4.25
ANOVA of students' gain scores of average SRL by flipped pedagogy and learning ability

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Partial Eta Squared*
Corrected Model	1.122[a]	3	.374	1.203	.312	.029
Intercept	.534	1	.534	1.719	.192	.014
Flipped_Pedagogy	.308	1	.308	.991	.321	.008
Ability	.300	1	.300	.966	.328	.008
Flipped_Pedagogy * Ability	.488	1	.488	1.570	.213	.013
Error	37.299	120	.311			
Total	38.982	124				
Corrected Total	38.421	123				

[a.] = R Squared = .029 (Adjusted R Squared = .005)

The result showed no significant interaction effect between flipped pedagogy and learning ability in the improvement of the students' average SRL ability, with $F(1,120) = 4.888$, $p = .213$, $\eta^2 p = .013$.

For the two-way MANOVA of the subscales of the SRL abilities, the test of the assumption of homogeneity of covariance was carried out using Box's test of equality of covariance matrices, using $p < .001$ as a criterion. The result found no significant differences between the covariance matrices, with Box's M (110.576) = .002. Therefore, the assumption of homogeneity of covariance was not violated and the MANOVA was conducted.

Table 4.26 shows the result of the two-way MANOVA. Using Wilks' lambda (λ), the main effect of flipped pedagogy on the linear combination of the subscales of SRL abilities was not significant, with Wilks' $\lambda = .987$, $F(6, 115) = .246$, $p = .960$. Furthermore, the interaction effect on the linear combination of the subscales of SRL abilities by flipped pedagogy and learning ability was not significant, with Wilks' $\lambda = .933$, $F(6, 115) = 1.374$, $p = .231$. Therefore, there was no difference on the linear combination of the SRL abilities subscales by flipped pedagogy, nor any interaction effect on the linear combination of SRL abilities subscales by flipped pedagogy and learning ability.

Table 4.26
Result of the MANOVA of the subscales of the SRL abilities by pedagogy and learning ability

Effect		*Value*	*F*	*Hypothesis df*	*Error df*	*Sig.*	*Partial Eta Squared*
Flipped Pedagogy	Pillai's Trace	.013	.246[b]	6.000	115.000	.960	.013
	Wilks' Lambda	.987	.246[b]	6.000	115.000	.960	.013
	Hotelling's Trace	.013	.246[b]	6.000	115.000	.960	.013
	Roy's Largest Root	.013	.246[b]	6.000	115.000	.960	.013
Ability	Pillai's Trace	.059	1.198[b]	6.000	115.000	.312	.059
	Wilks' Lambda	.941	1.198[b]	6.000	115.000	.312	.059
	Hotelling's Trace	.062	1.198[b]	6.000	115.000	.312	.059
	Roy's Largest Root	.062	1.198[b]	6.000	115.000	.312	.059
Flipped Pedagogy * Ability	Pillai's Trace	.067	1.374[b]	6.000	115.000	.231	.067
	Wilks' Lambda	.933	1.374[b]	6.000	115.000	.231	.067
	Hotelling's Trace	.072	1.374[b]	6.000	115.000	.231	.067
	Roy's Largest Root	.072	1.374[b]	6.000	115.000	.231	.067

[a.] = Design: Intercept + Flipped_Pedagogy + Ability + Flipped_Pedagogy * Ability
[b.] = Exact statistic

4.2.6.2 Learning Achievement (LA)

Independent sample t-tests for the gain scores of students' LA by learning ability in different flipped pedagogies (FPOE and TFC)

Independent sample *t*-tests were employed to determine whether there was a difference in the gain scores of LA between students with different learning abilities in different flipped pedagogies. The results are summarized in Table 4.27 and Table 4.28.

Table 4.27
Result of the independent sample t-test of gain scores of LA by learning ability in the FPOE

Measurement	Gain scores (posttest-pretest)					
	Higher learning ability (n = 32)		Lower learning ability (n = 31)			
	M	*SD*	*M*	*SD*	*t*	*Sig. (2-tailed)*
Learning achievement (LA)	42.250	12.521	33.807	10.445	2.902 [a]	.005

[a] = Equal variances assumed with p > .05 for Levene's tests.
[b] = Equal variances not assumed with p < .05 for Levene's tests.

In Table 4.27, significant result from the *t*-test of the gain scores among students with different learning abilities was obtained regarding the LA in the FPOE approach, with *t*(61) = -2.902, *p* = .005 (two-tailed). On average, the improvement of LA of the students with HL (*M* = 42.250, *SD* = 12.521) was significantly higher than that of the students with LL (*M* = 33.807, *SD* = 10.445), with *t*(61) = 2.902, *p* = .005 in the FPOE approach.

Table 4.28

Result of the independent sample t-test of gain scores of LA by learning ability in the TFC

Measurement	Gain scores (posttest-pretest)					
	Higher learning ability (*n* = 31)		Lower learning ability (*n* = 30)			
	M	*M*	*M*	*SD*	*t*	*Sig. (2-tailed)*
Learning achievement (LA)	41.194	41.194	33.467	9.313	2.731 [a]	.008

[a] = Equal variances assumed with p > .05 for Levene's tests.
[b] = Equal variances not assumed with p < .05 for Levene's tests.

In Table 4.28, significant result from the *t*-test of the gain scores among students with different learning abilities was obtained regarding the LA in the TFC approach, with *t*(59) = -2.731, *p* = .008 (two-tailed). On average, the improvement of LA of the students with HL (*M* = 41.194, *SD* = 12.496) was significantly higher than that of the students with LL (*M* = 33.467, *SD* = 9.313), with *t*(59) = 2.731, *p* = .008 in the TFC approach.

Two-way between-subjects ANOVA of students' post-scores of LA by flipped pedagogy and learning ability

A two-way between-subjects ANOVA of the students' gain scores of LA was conducted to investigate whether there was an interaction effect between flipped pedagogy and learning ability. For the ANOVA, the assumption of homogeneity of variance was met prior to the test, with a non-significant result of Levene's test, *F*(3,120) = .906, *p* = .440. Without violating the assumption of the test, the ANOVA was conducted. Table 4.29 shows the result of the two-way ANOVA of the LA.

Table 4.29
ANOVA of students' gain scores of LA by flipped pedagogy and learning ability

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Partial Eta Squared*
Corrected Model	2048.106[a]	3	682.702	5.343	.002	.118
Intercept	175953.588	1	175953.588	1377.045	.000	.920
Flipped_Pedagogy	15.101	1	15.101	.118	.732	.001
Ability	2025.437	1	2025.436861	15.851	.000	.117
Flipped_Pedagogy * Ability	3.978	1	3.978	.031	.860	.000
Error	15333.144	120	127.776			
Total	194089.000	124				
Corrected Total	17381.250	123				

[a.] = R Squared = .118 (Adjusted R Squared = .096)

The result showed no significant interaction effect between flipped pedagogy and learning ability in the improvement of the students' LA, with $F(1,120) = .031$, $p = .860$, $\eta^2 p < .001$.

4.2.6.3 Science Process Skills (SPS)

Independent sample t-tests for the gain scores of students' SPS by learning ability in different flipped pedagogies (FPOE and TFC)

Independent sample *t*-tests were employed to determine whether there were differences in the gain scores of SPS between students with different learning abilities in different flipped pedagogies. The results are summarized in Table 4.30 and Table 4.31.

In Table 4.30, the results showed that the improvement of stating hypotheses skill of the students with HL ($M = 2.469$, $SD = 1.665$) was significantly higher than that of the students with LL ($M = .581$, $SD = 2.248$), with $t(61) = -3.797$, $p < .001$, in the FPOE approach.

Table 4.30

Results of the independent sample t-tests of the gain scores of SPS by learning ability in the FPOE

Measurement	Gain scores (posttest-pretest)					
Science Process Skills (SPS)	Lower learning ability (*n* = 31)		Higher learning ability (*n* = 32)			*Sig. (2-tailed)*
	M	*SD*	*M*	*SD*	*t*	
Observation	-.355	1.380	.125	1.185	-1.483[a]	.143
Communication	-.194	1.447	.156	1.816	-.844[a]	.402
Classification	.129	1.432	.406	1.316	-.800[a]	.427
Measurement	.516	1.546	1.000	1.295	-1.348[a]	.183
Prediction	.387	1.308	.2188	1.362	.500[a]	.619
Inference	.452	1.502	-.188	1.447	1.720[a]	.090
Overall BSPS	.9355	5.459	1.719	4.386	-.629[a]	.532
Identifying variables	2.032	2.442	2.188	3.095	-.221[a]	.826
Stating hypotheses	.581	2.248	2.469	1.665	-3.797[a]	.000
Operational defining	.581	1.689	.656	1.961	-.164[a]	.870
Designing investigation	.516	1.092	.438	.878	.316[a]	.753
Graphing and interpreting data	1.129	1.803	.750	1.459	.197[a]	.362
Overall ISPS	4.839	4.465	6.500	4.649	-1.446[a]	.153

[a] = Equal variances assumed with $p > .05$ for Levene's tests.

Table 4.31

Results of the independent sample t-tests of the gain scores of SPS by learning ability in the TFC

Measurement	Gain scores (posttest-pretest)					
Science Process Skills (SPS)	Lower learning ability (*n* = 30)		Higher learning ability (*n* = 31)			*Sig. (2-tailed)*
	M	*SD*	*M*	*SD*	*t*	
Observation	-.300	.837	.000	1.438	-.992[a]	.325
Communication	-.200	1.064	-.484	1.651	.801[b]	.427
Classification	-.200	.961	-.161	1.463	-.122[a]	.904
Measurement	.333	1.348	.323	1.376	.031[a]	.976
Prediction	.300	1.179	.065	1.365	.720[a]	.474
Inference	.100	1.269	-.419	1.478	1.470[a]	.147
Overall BSPS	.033	3.548	-.677	5.224	.620[a]	.538
Identifying variables	1.467	2.921	1.484	2.528	-.025[a]	.980
Stating hypotheses	.000	1.554	.5161	1.947	-1.142[a]	.258
Operational defining	.4333	1.547	.484	1.691	-.122[a]	.904
Designing investigation	.767	1.040	.194	1.014	2.179[a]	.033
Graphing and interpreting data	.367	1.608	.323	1.376	.115[a]	.909
Overall ISPS	3.033	4.745	3.000	3.890	.030[a]	.976

[a] = Equal variances assumed with $p > .05$ for Levene's tests.

[b] = Equal variances not assumed with $p < .05$ for Levene's tests.

In Table 4.31, the results showed that only the improvement of designing investigation skill of the students with LL (*M* = .767, *SD* = 1.040) was significantly higher than that of the students with HL (*M* = .194, *SD* = 1.014), with $t(59)$ =2.179, p = .033, in the TFC approach.

Two-way between-subjects ANOVA of students' post-scores of overall BSPS and MANOVA of students' post-scores of BSPS subscales by flipped pedagogy and learning ability

A two-way between-subjects ANOVA of the students' gain scores of overall BSPS was conducted to investigate whether there was an interaction effect between flipped pedagogy and learning ability. For the ANOVA, the assumption of homogeneity of variance was met prior to the test, with a non-significant result of Levene's test, $F(3,120)$ = 2.206, p = .091. Without violating the assumption of the test, the ANOVA was conducted. Table 4.32 shows the result of the two-way ANOVA of the overall BSPS.

Table 4.32

ANOVA of students' gain scores of overall BSPS by flipped pedagogy and learning ability.

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Partial Eta Squared*
Corrected Model	102.887[a]	3	34.296	1.539	.208	.037
Intercept	31.299	1	31.299	1.405	.238	.012
Flipped_Pedagogy	84.268	1	84.268	3.782	.054	.031
Ability	.041	1	.041	.002	.966	.000
Flipped_Pedagogy *Ability	17.290	1	17.290	.776	.380	.006
Error	2674.081	120	22.284			
Total	2810.000	124				
Corrected Total	2776.968	123				

[a.] = R Squared = .037 (Adjusted R Squared = .013)

In Table 4.32, the result showed no significant interaction effect between flipped pedagogy and learning ability in the improvement of the students' overall BSPS, with $F(1,120)$ = .776, p = .380, $\eta^2 p$ = .006.

For the two-way MANOVA of the subscales of the BSPS, the test of the assumption of homogeneity of covariance was carried out using Box's test of equality of covariance matrices, using $p < .001$ as a criterion. The result suggested no significant differences between the covariance matrices, with Box's M (93.411) = .034. Therefore, the assumption of homogeneity of covariance was not violated and the MANOVA was conducted.

Table 4.33 shows the result of the two-way MANOVA. Using Wilks' lambda (λ), the main effect of flipped pedagogy on the linear combination of the subscales of BSPS was not significant, with Wilks' $\lambda = .941$, $F(6, 115) = 1.208$, $p = .307$. Furthermore, the interaction effect on the linear combination of the subscales of BSPS by flipped pedagogy and learning ability was not significant, with Wilks' $\lambda = .976$, $F(6, 115) = .465$, $p = .833$. Therefore, no difference was found on the linear combination of the BSPS subscales by flipped pedagogy, and there was no interaction effect on the linear combination of BSPS subscales by flipped pedagogy and learning ability.

Table 4.33
Result of the MANOVA of the subscales of the BSPS by pedagogy and learning ability

Effect		*Value*	*F*	*Hypothesis df*	*Error df*	*Sig.*	*Partial Eta Squared*
Flipped Pedagogy	Pillai's Trace	.059	1.208[b]	6.000	115.000	.307	.059
	Wilks' Lambda	.941	1.208[b]	6.000	115.000	.307	.059
	Hotelling's Trace	.063	1.208[b]	6.000	115.000	.307	.059
	Roy's Largest Root	.063	1.208[b]	6.000	115.000	.307	.059
Ability	Pillai's Trace	.098	2.092[b]	6.000	115.000	.059	.098
	Wilks' Lambda	.902	2.092[b]	6.000	115.000	.059	.098
	Hotelling's Trace	.109	2.092[b]	6.000	115.000	.059	.098
	Roy's Largest Root	.109	2.092[b]	6.000	115.000	.059	.098
Flipped Pedagogy * Ability	Pillai's Trace	.024	.465[b]	6.000	115.000	.833	.024
	Wilks' Lambda	.976	.465[b]	6.000	115.000	.833	.024
	Hotelling's Trace	.024	.465[b]	6.000	115.000	.833	.024
	Roy's Largest Root	.024	.465[b]	6.000	115.000	.833	.024

[a.] = Design: Intercept + Flipped_Pedagogy + Ability + Flipped_Pedagogy * Ability
[b.] = Exact statistic

Two-way between-subjects ANOVA of students' post-scores of overall ISPS and MANOVA of students' post-scores of ISPS subscales by flipped pedagogy and learning ability

A two-way between-subjects ANOVA of the students' gain scores of overall ISPS was conducted to investigate whether there was an interaction effect between flipped pedagogy and learning ability. For the ANOVA, the assumption of homogeneity of variance was met prior to the test, with a non-significant result of Levene's test, $F(3,120) = .823$, $p = .479$. Without violating the assumption of the test, the ANOVA was conducted. Table 4.34 shows the result of the two-way ANOVA of the overall ISPS.

Table 4.34
ANOVA of students' gain scores of overall ISPS by flipped pedagogy and learning ability

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Partial Eta Squared*
Corrected Model	263.775[a]	3	87.925	4.442	.005	.100
Intercept	2337.639	1	2337.639	118.104	.000	.496
Flipped_Pedagogy	218.026	1	218.026	11.015	.001	.084
Ability	20.529	1	20.529	1.037	.311	.009
Flipped_Pedagogy * Ability	22.244	1	22.244	1.124	.291	.009
Error	2375.160	120	19.793			
Total	5008.000	124				
Corrected Total	2638.935	123				

[a.] = R Squared = .100 (Adjusted R Squared = .077)

In Table 4.34, the result showed no significant interaction effect between flipped pedagogy and learning ability in the improvement of the students' overall ISPS, with $F(1,120) = 1.124$, $p = .291$, $\eta^2 p = .009$.

For the two-way MANOVA of the subscales of the ISPS, the test of the assumption of homogeneity of covariance was carried out using Box's test of equality of covariance matrices, using $p < .001$ as a criterion. The result suggested no significant differences between the covariance matrices, with Box's M (37.673) = .863. Therefore, the assumption homogeneity of covariance was not violated and the MANOVA was conducted.

Table 4.35 shows the result of the two-way MANOVA. Using Wilks' lambda (λ), the main effect of flipped pedagogy on the linear combination of the subscales of ISPS was significant, with Wilks' $\lambda = .839$, $F(5, 116) = 4.442$, $p = .001$. However, the interaction effect on the linear combination of the subscales of ISPS by flipped pedagogy and learning ability was not significant, with Wilks' $\lambda = .955$, $F(5, 116) = 1.099$, $p = .365$. Therefore, there was a difference on the linear combination of the ISPS subscales by flipped pedagogy but there was no interaction effect on the linear combination of ISPS subscales by flipped pedagogy and learning ability.

Table 4.35

Result of the MANOVA of the subscales of the ISPS by pedagogy and learning ability

Effect		*Value*	*F*	*Hypothesis df*	*Error df*	*Sig.*	*Partial Eta Squared*
Flipped Pedagogy	Pillai's Trace	.161	4.442[b]	5.000	116.000	.001	.161
	Wilks' Lambda	.839	4.442[b]	5.000	116.000	.001	.161
	Hotelling's Trace	.191	4.442[b]	5.000	116.000	.001	.161
	Roy's Largest Root	.191	4.442[b]	5.000	116.000	.001	.161
Ability	Pillai's Trace	.134	3.586[b]	5.000	116.000	.005	.134
	Wilks' Lambda	.866	3.586[b]	5.000	116.000	.005	.134
	Hotelling's Trace	.155	3.586[b]	5.000	116.000	.005	.134
	Roy's Largest Root	.155	3.586[b]	5.000	116.000	.005	.134
Flipped Pedagogy * Ability	Pillai's Trace	.045	1.099[b]	5.000	116.000	.365	.045
	Wilks' Lambda	.955	1.099[b]	5.000	116.000	.365	.045
	Hotelling's Trace	.047	1.099[b]	5.000	116.000	.365	.045
	Roy's Largest Root	.047	1.099[b]	5.000	116.000	.365	.045

[a.] = Design: Intercept + Flipped_Pedagogy + Ability + Flipped_Pedagogy * Ability

[b.] = Exact statistic

4.2.6 Summary of the Quantitative Analysis

The findings from the quantitative analysis to address the first three RQs are summarized in Table 4.36.

Table 4.36
Summary of the quantitative results (p(two-tailed)) for addressing RQ1, RQ2 and RQ3

Research Question	RQ1			RQ2^	RQ3+	
Approach Ability Type of test	FPOE / paired[1]	TFC / paired[1]	gain[2]	All / ANOVA[3]	FPOE higher/ lower gain[2]	TFC higher/ lower gain[2]
Goal setting	.196	.992	.389	.012*	.260	.439
Environmental structuring	.462	.460	.296	.171	.244	.033*
Task strategies	.571	.831	.583	.064	.402	.624
Time management	.036	.300	.445	.012*	.234	.289
Help seeking	.511	.868	.719	.129	.302	.454
Self-evaluation	.104	.341	.539	.042	.190	.074
Average SRL ability	.107	.825	.313	.017*	.119	.849
LA	.000	.000	.744	.025*	.005	.008
Observation	.499	.333	.870		.143	.325
Communication	.939	.058	.232		.402	.427
Classification	.123	.257	.057	N/A	.427	.904
Measurement	.000	.063	.085		.183	.976
Prediction	.076	.272	.605		.619	.474
Inference	.503	.362	.265		.090	.147
Overall Basic SPS	.035	.568	.051	.445	.532	.538
Identifying variables	.000	.000	.199		.826	.980
Stating hypotheses	.000	.251	.000		.000	.258
Operational defining	.009	.030	.605		.870	.904
Designing investigation	.000	.001	.997	N/A	.753	.033
Graphing and interpreting data	.000	.075	.037		.362	.909
Overall Integrated SPS	.000	.000	.001	.199	.153	.976

1 = paired sample *t*-test between pre-and post-scores. 2 = independent sample *t*-test of gain scores. 3 = ANOVA of the post-scores among all pedagogies (FPOE vs. TFC vs. TC). * = significance in pos hoc tests. ^ = non-significant results on the linear combination of the subscales of SRL, BSPS, and ISPS by pedagogies (MANOVA). + = no interaction effects by ability and flipped approach on average SRL, LA, BSPS, ISPS (ANOVA), and linear combinations of SRL, BSPS, and ISPS subscales, respectively (MANOVA). N/A = not available on the employment of ANOVAs on subscales independently due to non-significant ANOVA results of the overall BSPS and ISPS.

For the quantitative analysis addressing RQ1, the results from the paired sample *t*-tests showed that the students' time-management ability, LA, overall BSPS and its subscales of measurement, the overall integrated SPS and all its subscales, including identifying variables, stating hypotheses, operational defining, designing investigation, and graphing and interpreting data skills, were significantly improved following the FPOE intervention. However, the results from the paired sample *t*-tests showed that the students' LA, overall integrated SPS and its subscales of identifying variables, operational defining, and designing investigation skills were significantly improved following the TFC intervention. Notably, the results from the independent sample *t*-tests of the gain scores showed that the improvement of the students' overall BSPS, as well as the overall integrated SPS and its subscales of stating hypotheses , and graphing and interpreting data skills in the FPOE pedagogical approach, were significantly higher than those in the TFC pedagogical approach.

For the quantitative analysis addressing RQ2, the results from the one-way between-subjects ANOVAs of the post-scores showed that only the students' average SRL ability and LA were significantly different among the flipped and traditional pedagogical approaches (FPOE, TFC, and TC). The results from the pairwise comparisons suggested that the FPOE pedagogical approach was more effective at improving the students' average SRL ability than the non-flipped TC. In particular, the results showed that the FPOE approach was more effective at improving the students' goal-setting and time management abilities than the TC pedagogy. On the other hand, the results from the pairwise comparisons also suggested that only the FPOE approach was more effective at improving the students' LA than the non-flipped TC approach. In addition, the results from MANOVAs ($\lambda s > 0.05$) showed that the effect of pedagogy on the linear combination of the students' SRL abilities subscales, BSPS subscales, and ISPS subscales were not significant.

For the quantitative analysis addressing RQ3, the results from the independent sample *t*-tests of the gain scores showed that the improvement of environmental structuring ability of the students with HL was significantly higher than that of the students with LL in the TFC approach.

Regarding LA, the results from the independent sample *t*-tests of gain scores showed that the improvement of LA of the students with HL was significantly higher than that of the students with LL in both the FPOE and TFC approaches. For SPS, the results from the independent sample *t*-tests of the gain scores showed that the improvement of stating hypotheses skill of the students with HL was significantly higher than that of the students with LL in the FPOE approach. Furthermore, the results from the independent sample *t*-tests of the gain scores showed that the improvement of designing investigation skill of the students with LL was significantly higher than that of the students with HL in the TFC approach. Finally, the results of the MANOVAs showed no interaction effect on the linear combination of SRL subscales, BSPS subscales, and ISPS subscales by flipped pedagogy and learning ability.

4.3 Qualitative Findings

To elaborate the significant quantitative results from the previous sections, the interviews with the students who had generally positive improvements and neutral/negative effects in both flipped learning approaches (FPOE and TFC) were analyzed. The qualitative analysis in this sequential explanatory design (Creswell, 2009; Creswell & Plano Clark, 2007) focuses on RQ4:

RQ4: How and to what extent do the FPOE and TFC help students with different learning abilities to improve their SRL abilities, LA, and SPS?

4.3.1 Sample Profile of The Interviewees

The qualitative analysis was conducted on interview data from 16 students across both flipped approaches who had either collective improvements or neutral/negative effects on LA, SRL abilities, and SPS. The FPOE sample included eight students: four boys (two higher achievers and two lower achievers) and four girls (two higher achievers and two lower achievers).

Similarly, the TFC sample also included eight students: four boys (two higher achievers and two lower achievers) and four girls (two higher achievers and two lower achievers). Table 4.37 shows the profiles of the interviewees selected for qualitative analysis, including the criteria for selection based on the effects of flipped approaches on the interviewees' SRL, LA, BSPS, and ISPS.

Table 4.37

Profile of the interviewees selected for qualitative analysis

Group / class (learning ability)	Impacts of FC	Identifiers (Gender)	Pre / Post scores							
			SRL (5)		LA (100)		BSPS (36)		ISPS (36)	
			Pre	Post	Pre	Post	Pre	Post	Pre	Post
FPOE / 2A (higher)	Positive	FPOE-H-P-1 (M)	3.55	4.27	11	55	22	30	10	23
		FPOE-H-P-2 (F)	3.63	3.85	15	72	26	26	18	28
	Neutral/ negative	FPOE-H-N-1 (M)	2.99	3.09	10	32	30	30	8	16
		FPOE-H-N-2 (F)	3.00	3.10	9	28	29	27	20	23
TFC / 2B (higher)	Positive	TFC-H-P-1 (F)	3.53	3.33	5	78	29	33	23	26
		TFC-H-P-2 (M)	4.03	4.26	12	70	29	34	27	30
	Neutral/ negative	TFC-H-N-1 (M)	3.10	2.62	13	34	31	32	28	25
		TFC-H-N-2 (F)	3.40	2.66	13	34	27	29	21	21
FPOE / 2C (lower)	Positive	FPOE-L-P-1 (F)	3.01	4.03	9	55	29	32	20	22
		FPOE-L-P-2 (M)	3.00	3.17	5	56	27	29	7	23
	Neutral/ negative	FPOE-L-N-1 (M)	2.82	2.75	8	36	12	12	14	14
		FPOE-L-N-2 (F)	3.00	3.00	6	39	29	20	12	15
TFC / 2D (lower)	Positive	TFC-L-P-1 (F)	3.60	4.00	6	48	18	27	9	20
		TFC-L-P-2 (M)	2.55	3.06	6	46	29	26	13	18
	Neutral/ negative	TFC-L-N-1 (F)	3.26	2.66	15	33	29	29	17	16
		TFC-L-N-2 (M)	2.80	2.06	13	28	29	25	17	16

Positive impact: ☐ Neutral impact: (blue) Negative impact: (orange)

4.3.2 Description of Coding Process, Codes, and Themes

Qualitative data analysis of the interview transcripts was conducted following Creswell's (2007) procedure of data analysis spiral. First, the interview transcripts were organized in computer files and input into NVivo 12, computer software for qualitative data analysis. Then, the interview transcripts were read several times to search for general themes. Meaningful text segments were located and assigned preliminary codes.

As mentioned in the previous chapter (Section 3.7.2), the text segments were coded in accordance with the set of pre-existing organization categories and theoretical sub-categories / themes (Creswell, 2007; Maxwell, 2013). All codes were classified under four organization categories, namely (a) benefits to SRL abilities, (b) benefits to LA, (c) benefits to SPS, and (d) the challenges of flipped approaches in this study.

The themes of (a) environmental structuring, (b) task strategies, (c) time management, and (d) self-evaluation (Barnard et al., 2009) belong to the organization category of the benefits to SRL abilities (n = 4). The themes of (a) observation, (b) measurement, (c) inference (Padilla et al., 1985), (d) identifying variables, (e) stating hypotheses, (f) designing investigation, and (g) graphing and interpreting data (Burns et al., 1985) belong to the organization category of benefits to SPS (n = 7). The themes of (a) sufficient time for activities, (b) learning new knowledge, (c) real-time feedback (Lo et al., 2017), and (d) better management of cognitive load (Abeysekera & Dawson, 2015) belong to the organization category of benefits to LA (n = 4). All these themes were identified throughout the content analysis. The themes of student-related and operation-related challenges (Betihavas et al., 2016) were also identified (n = *2*). In addition, no substantive category was identified inductively (Maxwell, 2013). In total, 18 themes (sub-categories) codes were developed. Table 4.38 summarizes the categories, themes, and codes developed in the qualitative analysis.

Table 4.38

Summary of the categories, themes, and codes identified in the qualitative analysis

Category	**Code of Theme / sub-category**	**Description**
Benefits to SRL abilities	ES: **E**nvironmental **s**tructuring	Finding a quiet place for online learning
	TS: **T**ask **s**trategies	Note-taking Reading and referring to textbook information
	TM: **T**ime **m**anagement	Watching videos and completing the quizzes before doing other homework Finding leisure time for online learning Arranging regular timeslot for online tasks
	SE: **S**elf-**e**valuation	Computerized and automated marking of quizzes in the LMS Teachers' comments on online tasks
Benefits to LA	ST: **S**ufficient **t**ime for activities	More time for discussion More time for drilling exercise More time for preparing test/exam
	LK: **L**earning new **k**nowledge	Learning extensive knowledge from online POE activities Learning extensive knowledge from scientific inquires
	RF: **R**eal-time **f**eedback from teachers (RF)	Real-time online feedback from teachers Quick feedback from teachers in lessons
	MC: Better **m**anagement of **c**ognitive load	Self-pacing in online learning Tailoring in-class learning
Benefits to SPS	O: **O**bservation	Real-time streaming on YouTube enables observing anytime and anywhere More in-class / online investigations / inquiries provided by teachers
	M: **M**easurement	More chance to make measurements Proper use of measurement tools Proper calculation with the measurement tools
	P: **P**rediction	More chance to make predictions in scientific scenarios
	I: **I**nference	Use of reasoning skill in drawing conclusions resulting from observations / evidence
	IV: **I**dentifying **v**ariables	More chance to identify variables through online/in-class investigations Determining the effect on results by changing one of the variables during prediction stage in the FPOE Identifying variables through the graphing function of mobile logger application
	SH: **S**tating **h**ypotheses	Participation in the pre-observation stage of the POE activities helps when making tentative explanations Feedback from the explanation stage of POE activities helps to propose reasonable hypotheses
	DI: **D**esigning **i**nvestigation	Guidance from experimental videos is useful for designing fair tests in the lessons

	GD: **G**raphing and interpreting **d**ata	Automated and real-time plotting function of graphs to externalize the effect of independent variable on dependent variable Teachers' clarification of students' misinterpretation of the plotted graph in terms of scales and labels of axes in the FPOE activities
Challenges for flipped approaches	**SC**: **S**tudent-related **C**hallenges	Initial struggles on familiarizing with the FC
		Heavy workload
		Lack of rapid out-of-class support from teachers
	OC: Operation-related **C**hallenges	Problems with accessing the online videos/streaming in LMS

The benefits identified were used to explain the quantitative findings, whereas the challenges identified could also be used to explain why some students did not improve in in their science learning in the FPOE / TFC approaches.

4.3.3 Presentation of Qualitative Findings

4.3.3.1 Counts of Codes and Quotes of Representative Students Responses

To have a clear understanding of how the students responded in the interviews, the number of identified codes was counted, and the representative student quotes are provided in Table 4.39.

Table 4.39
Data summary of the codes and representative student quotes

Code (*count*)	Representative student quotes (Identifier)
ES (*n* =3)	I was keen on watching the online videos at home right after school in the afternoon before my parents returned home. (TFC-H-P-2)
TS (*n* =9)	Yes, probably! I used to write down notes on my science notebook when watching the online videos. I would jot down something I did not fully understand first so that I could ask Miss Wong [science teacher] the issue after watching the videos. (TFC-H-P-1)
	I might also refer to my textbook when watching the videos so that I could obtain more information from the textbook. I would also pause the videos, check with more information from textbook if necessary, and carry on watching the videos. In addition, I would also re-watch the videos if I got confused with the information. (TFC-H-P-1)
TM (*n =10*)	I usually watched the videos before doing other homework. (FPOE-L-P-2)
	More time was spent on the weekend participating in the online experiment. I even gave up some shopping time with my close friends… (FPOE-H-N-1)

	Since we should observe the seedling growth every day, I set an alarm on my phone to remind me to look at the live-streaming and to plot the graphs. (FPOE-H-P-2)
SE (*n* =13)	I could check for my mistakes once I got the answers immediately after finishing the quizzes in Power-Lesson [LMS]. (TFC-L-N-1)
	Teachers' comments on the online [POE] exercise about drawing series and parallel circuits were very useful. (FPOE-H-P-2)
ST (*n* =12)	We could discuss more about the planning of the investigation…(FPOE-L-P-1)
	After finishing the investigations in the lessons, Miss Wong [science teacher] often gave us more time and guidance to work on the workbook exercises. (TFC-H-P-2)
	I like the extra booklets provided by the teachers… when we were doing the multiple-choice and structured questions in the lessons, I felt more confident. It helped me to prepare for the final exam, too. (FPOE-H-P-1)
LK (*n* =9)	The online learning [activities] were new and not only related to the content in the textbook. I really worked like a scientist on monitoring the growth of seedlings under different pH. (FPOE-H-P-2)
	We had to do many experiments [scientific inquiries] in the science lessons this year. Most were not similar to those experiments in the textbook. Some [of the investigations] were difficult but I think it was good for me to learn more science knowledge out of the textbook. (TFC-N-P-1)
RF (*n* =9)	I remember that you [science teacher] helped me to use the mobile logger app to draw [plot] a graph for the explanation stage in the online activity after I sent you a message in Power-Lesson [LMS]. (FPOE-H-P-2)
	Mr. Chow [science teacher] often gave us feedback on our online quiz results at the beginning of the lessons. (TFC-L-P-2)
MC (*n* =17)	Since watching the online video for the first time would only help me get the general idea of knowledge content, I would re-watch the videos. Especially, when I looked at the questions of the online exercise, I would think more thoroughly and watch the video again. I would pause at certain points of the video to answer the questions step-by-step. (TFC-H-P-1)
	In the experiment [investigation] about mealworms, my group finished so quickly that we were guided to use one extra method to study the gas exchanges of mealworms by using the mobile device [logger]. (FPOE-H-N-2)
O (*n* =11)	This was the first time for me to make observations in a science experiment through YouTube. It was a wonderful experience as I could even watch the growth of the seedlings at midnight! (FPOE-H-P-2)
	We had more chance to make observation in the science experiments [investigations], but I needed to observe the scientific scenarios carefully so that I would not misinterpret the results when drawing conclusions. (FPOE-L-P-2)
M (*n* =11)	…using mathematical method [skills] in a lot of experiments like finding the electric current, voltage, and resistance in different circuits… (FPOE-L-N-1)
	The use of a mobile logger instead of an indicator for the measurement of gas released from mealworms was more useful and direct. (FPOE-H-P-1)
	…calculating temperature change per gram of food when comparing the amount of [heat] energy released in the burning of different foods. I learned it through watching the experimental videos before carrying out the experiment

	[inquiry] in the lessons. (TFC-H-P-2)
P (*n* =6)	The online experiment required us to make reasonable predictions by ourselves in different situations. (FPOE-L-N-1)
I (*n* =4)	The observation from YouTube live-streaming and logger data helped me to explain how the seedlings grew with the change of temperature, light [intensity], and gas [content], and hence I could know which pH was the most suitable for the seedlings…(FPOE-L-N-2)
IV (*n* =13)	The science investigation [inquiry] of the factor affecting the resistance allowed me to think and choose the variable of material to be studied. I also conducted similar investigations by using length and thickness of resistive wire as an independent variable… (TFC-H-P-1)
	In the online learning [of the FPOE], I needed to predict the effect of light [intensity] on the [relative] humidity, as well as other independent variables such as the effect of pH on the height of seedlings, etc… It was a bit difficult at the beginning, but it enhanced my ability to find [identify] variables for the investigation. (FPOE-L-N-2)
	From the auto-plotted graph, I was able to identify the time on the x-axis as the independent variable and the concentration of carbon dioxide on the y-axis as the dependent variable…(FPOE-L-N-1)
SH (*n* =4)	It was so surprising that what I predicted in the first online [POE] activity of burning candles was totally different from what I had observed. This helped me to think more thoroughly to make a more reasonable explanation. (FPOE-H-P-2)
	The comments from Mr. Lee [science teacher] also guided me to clarify my tentative explanation of why a higher temperature caused lower relative humidity inside the gas jar. (FPOE-H-P-2)
DI (*n* =7)	The videos guided me through some experimental procedures, such as the steps for boiling a leaf in the iodine test…and helped me to design a fair test for photosynthesis. (TFC-L-P-1)
GD (*n* =9)	The change of light intensity and concentration of carbon dioxide [dependent variables] could be seen through the real-time plotted graph at different times. (FPOE-H-P-1)
	I remembered that I made a mistake comparing the carbon dioxide content in different jars as I just compared the shape of the curve without noticing that the scales of the graphs plotted under different pH were different. Fortunately, Miss Wong [science teacher] reminded us that the scale of CO_2 concentration was a thousand times more than the others. (FPOE-H-N-1)
SC (*n* =9)	I needed to figure out where I could find the instructional videos and experimental videos, as well as the materials such as PowerPoint and quizzes at the very beginning. (TFC-L-N-1)
	Our class already had a lot of homework in science, and the extra assignments in online activities further hindered me from going to bed early. (FPOE-L-N-2)
	…when I tried to submit the answers in the online quiz, I could not find any 'button' for submission in Power-Lesson [LMS]. I needed to redo the quiz several times after restarting my computer, but I still failed to do so. My teacher was unable to help me to solve this problem at that time…(TFC-L-N-2)
OC	I was unable to watch the videos when I returned to my home in Shenzhen on

(*n* =1)	the weekends. (FPOE-H-N-2)

There are many identified codes stressing the benefits of FC on SRL, LA, and SPS, suggesting that the significant quantitative findings were supported and could be explained by the qualitative evidence. In particular, the significant quantitative findings regarding the students' gains in time-management ability, LA, measurement, identifying variables, stating hypotheses, designing investigation, and graphing and interpreting data skills are all supported by the qualitative evidence. The analysis of the interview data also found several positive impacts of FC that had not been identified from the quantitative findings. These impacts include the improvements of students' task strategies and self-evaluation abilities, observation and prediction skills. Furthermore, some of the quotes regarding the ISPS subscales reveal inter-relationships, echoing the significant finding on the linear combination of the ISPS subscales by flipped pedagogy as suggested by the MANOVA result.

4.3.3.2 Counts of Categories, Themes, and Codes in Different Classifications

The analysis of the data is also presented in matrix form, which illustrates the counts of the identified categories, themes, and codes in different classifications of the groups (i.e., flipped pedagogical approaches [FPOE/TFC] and learning abilities [lower/higher]). Table 4.40 shows a matrix of the qualitative analysis.

In Table 4.40, there are more codes identified in the FPOE approach in terms of SRL, especially the time-management ability, echoing the quantitative finding of significant gain in time-management ability of the students in the FPOE approach (RQ1). Several codes regarding environmental structuring ability were identified for the students with HL in the TFC approach. These findings provide evidential supports for the quantitative findings from the independent sample *t*-test of the gain scores of SRL subscales (RQ3).

Table 4.40

Matrix of the counts of categories and codes identified at different approaches

		FPOE			TFC			
		Lower ability	Higher ability	Sub-total	Lower ability	Higher ability	Sub-total	Total
Category	**Benefits to SRL abilities**	**8**	**17**	**25**	**6**	**4**	**10**	**35**
Code	**ES**	**0**	**1**	**1**	**0**	**2**	**2**	**3**
Code	**TS**	**3**	**3**	**6**	**1**	**2**	**6**	**9**
Code	**TM**	**2**	**7**	**9**	**0**	**1**	**1**	**10**
Code	**SE**	**3**	**6**	**9**	**3**	**1**	**4**	**13**
Category	**Benefits to LA**	**10**	**20**	**30**	**5**	**12**	**17**	**47**
Code	**ST**	**2**	**6**	**8**	**0**	**4**	**4**	**12**
Code	**LK**	**1**	**3**	**4**	**2**	**3**	**5**	**9**
Code	**RF**	**3**	**4**	**7**	**1**	**1**	**2**	**9**
Code	**MC**	**4**	**7**	**11**	**2**	**4**	**6**	**17**
Category	**Benefits to SPS**	**20**	**30**	**50**	**6**	**9**	**15**	**65**
	BSPS	***10***	***13***	***23***	***3***	***6***	***9***	***32***
Code	**O**	**4**	**5**	**9**	**0**	**2**	**2**	**11**
Code	**M**	**2**	**5**	**7**	**1**	**3**	**4**	**11**
Code	**P**	**2**	**2**	**4**	**1**	**1**	**2**	**6**
Code	**I**	**2**	**1**	**3**	**1**	**0**	**1**	**4**
	ISPS	***10***	***17***	***27***	***3***	***3***	***6***	***33***
Code	**IV**	**4**	**6**	**10**	**1**	**2**	**3**	**13**
Code	**SH**	**1**	**3**	**4**	**0**	**0**	**0**	**4**
Code	**DI**	**2**	**2**	**4**	**2**	**1**	**3**	**7**
Code	**GD**	**3**	**6**	**9**	**0**	**0**	**0**	**9**
Category	**Challenges**	**2**	**2**	**4**	**3**	**3**	**6**	**10**
Code	**SC**	**2**	**1**	**3**	**3**	**3**	**6**	**9**
Code	**OC**	**0**	**1**	**1**	**0**	**0**	**0**	**1**

Regarding LA, numerous codes were identified in both flipped learning approaches, with most being for the students with HL. This qualitative finding is in line with the significant gains in LA in both flipped approaches (RQ1), as well as the larger significant gains of LA among the students with HL (RQ3).

Regarding SPS, many codes were identified in both flipped approaches, with more codes for the FPOE approach, and especially for the students with HL. The qualitative results are in alignment with the significant gains in measurement, identifying variables, stating hypotheses, designing investigation, and graphing and interpreting data skills among students in the FPOE (RQ1) suggested by the quantitative analysis. Codes for the gains of identifying variables and designing investigation of the students in the TFC approach were also identified (RQ1). Moreover, the qualitative evidence explained (a) why the students with HL had improved their stating hypotheses skills more significantly than those with LL in the FPOE (RQ3); and (b) why the students with LL had improved their designing investigation skills more significantly than those with HL in the TFC (RQ3). Only evidence regarding the gain in operational defining skills was lacking in the qualitative analysis. (see Table 4.36 for a summary of the quantitative results).

4.4 Summary

This chapter initially illustrated the satisfactory reliability levels of the OSLQ, BAPS, and TIPS-II instruments for the quantitative analysis. Assumption checking for normality, and the identification and treatment of outliers were also discussed before analysing the quantitative and qualitative data. This chapter also illustrated the quantitative results from different inferential statistical analyses to address the first three research questions. Finally, this chapter provided sufficient qualitative evidence in different classifications to explain most of the quantitative results. The fourth research question was comprehensively addressed. Further in-depth discussions on the quantitative and qualitative findings and their triangulation are made in the next chapter.

Chapter 5: Discussion

5.1 Introduction

In the previous chapter, the analysis and results from the quantitative and qualitative data were presented. This chapter primarily summarizes and discusses the major findings to address the following four RQs:

RQ1: Can the FPOE improve students' SRL abilities, LA, and SPS in comparison with the TFC?

RQ2: Are there differences in the improvements of students' SRL abilities, LA, and SPS among different pedagogical approaches (FPOE vs. TFC vs. TC)? If yes, which is the most effective?

RQ3: Do student learning abilities (lower and higher) affect the improvements of their SRL abilities, LA, and SPS in different flipped pedagogical approaches (FPOE and TFC)?

RQ4: How and to what extent do the FPOE and TFC help students with different learning abilities to improve their SRL abilities, LA, and SPS?

In addition, this chapter discusses several limitations and difficulties encountered during this research in terms of the perspectives of students, teacher, and curriculum. Finally, recommendations for future research and practice regarding the FPOE are suggested.

5.2 Discussion

This section summarizes the results from the quantitative and qualitative analysis with the triangulation of the quantitative data from the qualitative evidence. The significant findings are evaluated and discussed considering the existing body of contemporary research evidence regarding the efficacy of the flipped learning approach on students' SRL abilities and SL comprising LA and SPS. The study findings are also compared and contrasted with other existing literature evidence about students' SRL, LA, and SPS outside the FC context but within the context of SRL, POE, and TEL embraced in this research.

5.2.1 The Impacts of the Modified Flipped Classroom on Students' SRL Abilities, LA, and SPS Compared with the Traditional Flipped Classroom (RQ1 and RQ4)

5.2.1.1 Self-Regulated Learning (SRL) Abilities

The results from the paired sample *t*-tests showed that the students' time-management ability was significantly improved following the FPOE intervention, whereas there was no such improvement among students in the TFC group. The quantitative result is supported by the qualitative findings that the activities in the FPOE approach required students to prioritize and find extra time for online learning, and to arrange regular timeslots for online tasks, especially the online technology-enhanced POE investigations that integrated with the SRL strategy. For example, one student (FPOE-H-P-2) in the FPOE group stated that, "since we should observe the seedling growth every day, I decided to set an alarm on my phone to remind me to look at the live-streaming and to plot the graphs."

Such findings are consistent with Lai and Hwang's (2016) research which found that students had higher awareness of time management in a self-regulated flipped classroom (SRFC) compared with those in a TFC in an elementary mathematics class. Çakıroğlu and Öztürk (2017) also discovered that students allocated time for watching the videos prior to the lesson in a punctual and regular manner in the FC environment. Moreover, students participating in online POE activities using mobile dataloggers may also need to manage their time well during long-lasting investigations, especially when making observations and recording data via an online system through their own initiatives (Tho & Yeung, 2018).

In contrast, the quantitative results from the paired sample *t*-tests between pre-scores and post-scores revealed no significant improvements in the average SRL ability and its subscales other than time management (i.e., goal-setting, environmental structuring, task strategies, help-seeking, and self-evaluation) in both the FPOE and TFC. The results of the independent sample *t*-tests of the gain scores also showed no significant differences in the improvements of the students' average SRL and its subscales between the FPOE and TFC approaches. These quantitative findings are aligned with Sun et al.'s (2017) study which found that students in the FC had no significant differences, according to an ANCOVA, with the control group of distance learning (DL) in terms of the average SRL ability and its categories of goal-setting, environmental structuring, task strategies, and self-evaluation.

One possible cause of the insignificant differences regarding the improvements of these SRL abilities between the FPOE and TFC might be due to the similarity of goal orientation among the students who participated in the two flipped approaches (Sun et al., 2017). According to Hagen and Weinstein (1995), there are two goals, namely the mastery goal and performance goal, that influence students' SRL and self-efficacy. The mastery goal primarily focuses on the learning process, mastering the course materials, seeking challenging assignments, and employing more effective learning strategies during study, whereas the performance goal solely focuses on learning outcomes such as grades and rewards, with less effective learning strategies preferred by students. A complementary combination of these two goals is vital for students to improve their self-regulation in their learning. However, students might only establish a high performance goal in the FPOE and TFC, as several of them reported in the interviews that the videos and quizzes in the FCs helped them revise content knowledge and gain extra time for drilling exercises, preparing for tests, and exams in the lessons. This factor undoubtedly prevents students from self-evaluating in the two FCs because they depend more heavily on rehearsal strategy than elaboration during online learning (Sun et al., 2017). The lack of segments or codes regarding goal-setting (identified from the student interviews) might also suggest a lack of the mastery goal among students learning in the two flipped approaches. Such similarity of orientation of higher performance goals and lower mastery goals might, thus, hinder the students to improve their SRL abilities, including environmental structuring, task strategies, help-seeking, and self-evaluation very differently between the FPOE and TFC.

Moreover, despite help-seeking behavior being regarded as a factor that can be easily influenced by the external setting of teaching and learning activities in the FCs (Sun et al., 2017), the results demonstrate that this is not the case in the FPOE and TFC in this study. Not surprisingly, the students, like other Chinese students in East Asian societies, were generally more reluctant to ask for help and express ideas than their counterparts in Western countries (Ho, 2009).

Although there were insignificant quantitative results regarding the aforementioned SRL subscales, qualitative evidence about environmental structuring, task strategies, and self-evaluation were identified from the student interviews, suggesting that students still employed these types of SRL strategies in their learning to some extent through the two flipped pedagogical approaches. Such discrepancy of findings might be due to the students' SRL abilities being internally stable and requiring longer to develop and become established (Sun et al., 2017). Consequently, the students' self-reports of their SRL abilities in the OSLQ questionnaire might not agree with the qualitative findings from the in-depth interviews.

5.2.1.2 Learning Achievement (LA)

The results from the paired sample *t*-tests showed that the students' LA was significantly improved following the FPOE and TFC interventions. The insignificant result of the independent sample *t*-test on the gain scores of the students' LA between the FPOE and TFC suggested that the improvements of LA were no different between the two flipped pedagogical approaches. This quantitative finding can be explained by numerous statements from the student interviews. In the interviews, students from both flipped approached reported (a) having more time for discussion, drilling exercises, and preparing for examinations, (b) learning more extensive knowledge from the textbook, (c) having real-time feedback, and (d) receiving tailored learning opportunities during the in-class inquiry-based learning. On the other hand, the students also stated that they (a) had real-time feedback online and (b) could learn in a self-pacing manner in the online pre-class learning. For instance, one student (TFC-H-P-2) in the TFC group reported that, "after finishing the investigations in the lessons, Miss Wong [science teacher] often gave us more time and guidance for working on the workbook exercises." Another student (FPOE-H-N-2) in the FPOE group also stated that, "in the experiment [investigation] about mealworms, my group finished so quickly that we were guided to use one extra method to study the gas exchanges of mealworms by using a mobile device [logger]."

These findings are coherent with previous studies on flipped learning in science, physics, mathematics, and chemistry (Çetinkaya, 2017; Lo et al., 2018; Olakanmi, 2017; Schultz et al. 2014). For example, regarding in-class learning, Lo et al. (2018) stated that teachers could tailor student learning by skipping some parts that could be learned through videos, saving time to assists students by elaborating on concepts and clarifying misunderstandings in the lesson. Çetinkaya (2017) suggested that teachers could invest more time in research-based learning, active learning, peer learning, and cooperative learning to arouse student interest and to improve their high-level thinking skills in lessons with large class sizes. Regarding online learning, Lo et al. (2018) and Schultz et al. (2014) claimed that the flipped approach allowed students to pause, rewind, and replay to evaluate what they have learned from online videos. Such a feature enables students to learn content at their own pace in the online environment (Lo et al., 2018), and hence, to manage the cognitive load of learning better (Abeysekera & Dawson, 2015).

Nevertheless, the insignificant differences regarding LA between the FPOE and TFC approaches contradict the findings from some similar studies that compared a modified FC with a conventional FC (e.g., Çetinkaya, 2017; Lai & Hwang, 2016; Zainuddin, 2018). For example, Zainuddin (2018) claimed that students who participated in his modified FC with a gamification approach outperformed those who participated in a traditional FC. Lai and Hwang (2016) revealed that their modified FC that embedded an SRL strategy was more effective at improving students' LA than a conventional FC without SRL elements.

One possible reason for such contradiction is the greater influence of the in-class active-learning strategies employed in the flipped approaches in this study. Jensen et al. (2015) stressed that the gains they found in student learning were probably due to the active-learning style of instruction in the classroom rather than whether the lesson was flipped or not (Jensen et al., 2015). Indeed, neither of the aforementioned studies employed an inquiry-based learning strategy, but focused on lower mastery-level activities (Anderson & Krathwohl, 2001), such as completing web-assisted measurements and evaluating quizzes (Çetinkaya, 2017), discussing and solving problems provided by the teacher (Lai & Hwang, 2016), and group discussions and student presentations (Zainuddin, 2018) integrated in the in-class learning. These flipped approaches depended heavily on the features of online pre-class learning (e.g., the online gamification and competition; Zainuddin, 2018) to enhance student learning.

As several pieces of the reviewed literature suggested that integrating science inquiry in the lesson increases student learning performance (Blanchard et al. 2010; Lee & Ng, 2004), such inquiry-based learning activities in the in-class component of the FPOE and TFC would contribute to the improvement of students' LA in similar degree in this study.

Other possible causes, such as the nature of POE activities in the FPOE approach, which mainly focuses on developing students' SPS rather than learning performance, may also contribute to the insignificant difference in results between the FPOE and the TFC in this study.

5.2.1.3 Science Process Skills (SPS)

5.2.1.3.1 Basic Science Process Skills (BSPS)

The results from the paired sample *t*-tests showed significant improvement in the students' measurement skill only in the FPOE approach, but not in the TFC approach. These findings are supported by the interview analysis that students in the FPOE approach had more chances to make measurements, and they would make proper use of measurement tools and proper calculation during the in-class inquires. For example, a student (FPOE-H-P-1) in the FPOE group reported that, during the in-class scientific inquiry, "the use of a mobile logger instead of an indicator for the measurement of gas released from mealworms was more useful and direct."

Moreover, the higher number of codes identified in the FPOE group (n = 7) than that in the TFC (n = 4) is in line with the quantitative mentioned above. Such a finding also aligns with

Tho and Yeung's (2018) finding that secondary school students perceived positively the use of a remote laboratory for measuring and gathering data from the online investigations. Furthermore, Geban et al. (1992) emphasized that computer-simulated experiments with a variety of problem-solving activities could acquire a wider variety of SPS, including measurement and data collection. Thus, the increased exposure and experience of using technology-enhanced measurement tools in the online POE activities in the FPOE approach could cultivate students' measurement skills gradually in this study.

In addition to measurement skill, the evidence from the interview indicated that the students had more chances to predict scientific scenarios in the FPOE approach, despite of the insignificant results obtained from the paired sample *t*-test regarding the their prediction skills in both the FPOE and TFC approaches. For example, one student (FPOE-L-N-1) in the FPOE approach stated that, "the online experiment required us to make reasonable predictions by ourselves in different situations."

This finding is consistent with Geban et al.'s (1992) suggestion that greater participation in problem-based inquiries enhances students' SPS, including the skill of making predictions. Moreover, a main reason for such an improvement is probably due to the advantages of the technology-enhanced POE activities on student learning. As suggested by Kearney et al. (2001), students were more confident to make initial predictions about the investigation in the multimedia-supported POE activities in the form of video clips, as students were more comfortable compared with the actual handling of laboratory equipment in numerous POE situations. However, there is also no significant difference in the gain scores of prediction skill among students in the FPOE and TFC approaches. This insignificance may be due to the limitations of the POE activities in the FPOE approach, as the students could only conduct the online POE activities individually without any group discussion of the ideas of the predictions, and without the teacher's immediate guidance to reach a consensus during the process. As students who made incorrect and unreasonable predictions often explain their results based on those predictions (White & Gunstone, 1992), the POE approach should be integrated in a cooperative manner that allows student to discuss, critique, and share with a group during the prediction and explanation phases under teacher guidance to facilitate the integrated acquisition of conceptual and procedural knowledge in science (Cinici & Demir, 2013). Such a limitation of the POE activities in the FPOE approach might also contribute to the insignificant results of the *t*-tests of student gains in inference skill and the LA between the FPOE and TFC approaches in this study.

Surprisingly, no significant result regarding the observation skill among students between the FPOE and TFC was obtained, although qualitative evidence was identified among the students in the FPOE approach. Several students reported that the real-time streaming features allowed them to observe anytime and anywhere (Tho & Yeung, 2018). For example, one student (FPOE-H-P-2) in the FPOE group stated that, "this was the first time for me to make observations in a science experiment through YouTube. It was a wonderful experience as I could even watch the growth of the seedlings at midnight!" The students also reported that more observation opportunities were provided through the in-class science inquiries and online POE activities, which enabled them to observe accurate and repeated replica of scientific demonstrations (Kearney et al., 2001). For example, one student (FPOE-L-P-2) in the FPOE group stated that, "we had more chance to make observation in the science experiments [investigations], but I needed to observe the scientific scenarios carefully so that I would not misinterpret the results when drawing conclusions." It is suspected that the lack of significant difference quantitatively could be due to the questions related to the observation skill in the

BAPS that are too easy and direct to differentiate students' observation skills. Perhaps other sources of data, such as lesson observation of students' uses of the BSPS are necessary in future studies.

Regarding the communication and classification skills, no significant results from the quantitative analysis nor insightful qualitative evidence were obtained. Collectively, the results from the independent sample *t*-test indicate that the students' gain in the overall BSPS in the FPOE approach was significantly higher than that in the TFC approach, suggesting the FPOE was more effective at improving the students' BSPS in general.

5.2.1.3.2 Integrated Science Process Skills (ISPS)

The results from the paired sample *t*-tests showed that the students' identifying variables, operational defining, and designing investigation skills were significantly improved in both the FPOE and TFC approaches. Qualitative findings such as (a) having more chances to identify variables through the online/in-class learning; (b) determining the effect on results by changing one of the variables during the prediction stage in the POE activities; and (c) identifying variables through the graphing function of mobile logger application in the FPOE, were identified regarding improving the identifying variables skill. For example, a student (TFC-H-P-1) in the TFC group stated that, "the science investigation [inquiry] of the factor affecting the resistance allowed me to think and choose the variable of material to be studied. I also conducted similar investigations by using length and thickness of resistive wire as an independent variable…" Another student (FPOE-L-N-1) in the FPOE group also stated that, "from the auto-plotted graph, I was able to identify the time on the x-axis as the independent variable and the concentration of carbon dioxide on the y-axis as the dependent variable…" Also, the qualitative finding that the students could receive adequate and useful guidance from experimental videos for designing fair tests in the lessons was identified regarding the designing investigation skill. For instance, a student (TFC-L-P-1) in the TFC group stated that, "the videos guided me through some experimental procedures, such as the steps for boiling a leaf in the iodine test…and helped me to design a fair test for photosynthesis."

These findings corroborate the conclusion drawn by Kramer et al. (2018) that interactive online tutorials were beneficial for developing students' experimental skills. The features of the interactive tutorials, which include (a) module introductions in texts and animations, (b) challenging questions and specific feedback for students, and (c) accessibility for students to track their progress and review entire modules at any time, are synonymous with the characteristics of the online sessions of the flipped approaches in this study. In addition, the add-on technology-enhanced POE activities with the use of mobile loggers in the FPOE could improve students' scientific abilities (Tho & Yeung, 2018), which might include the three improved subscales of ISPS. However, there were no significant differences in the improvements of these skills between these two flipped approaches, even though the qualitative evidence was identified from the students who participated in the FPOE group (identifying variable skill: FPOE: n = 10, TFC: n = 3; designing investigation skill: FPOE: n = 4, TFC: n = 3). Moreover, there is no qualitative evidence to explain the improvement of the operational defining skill in either the FPOE or TFC, suggesting that this skill might be implicitly rooted in the students' viewpoints. The gain in the operation defining skill of the students is consistent with the gain in their measurement skill because these two skills are interdependent. In particular, the operation defining skill relates to how to design and perform the measurement properly in an investigation (Ostlund, 1992; Rezba et al., 2003).

The results from the paired sample t-tests showed that the students' stating hypotheses skill and graphing and interpreting data skill were significantly improved only in the FPOE approach. Consistently, the results from the independent sample *t*-tests of gain scores showed that the improvements of these two skills of the students in the FPOE approach were significantly higher than those in the TFC, suggesting that the FPOE approach was more effective at enhancing the students' stating hypotheses skill and graphing and interpreting data skill than the TFC approach.

Regarding the skill of stating hypotheses, students in the FPOE approach reported numerous supporting evidence for their improvement, including (a) the advantage of participating in the pre-observation stage of the POE activities to help them to make tentative explanations; and (b) the feedback received from the explanation stage of POE activities to help them to propose reasonable hypotheses. For example, a student (FPOE-H-P-2) in the FPOE group stated that, "it was so surprising that what I predicted in the first online [POE] activity of burning candles was totally different from what I had observed. This helped me to think more thoroughly to make a more reasonable explanation." These findings might be aligned with the significant improvement of the students' prediction skill in the FPOE approach, which required students to employ problem-solving skills in their active searching to hypothesize tentative and rational explanations in the prediction phase of the POE activities (Geban et al., 1992). Kramer et al. (2018) suggested that the online interactive tasks could provide students with more opportunities to revisit and modify their ideas, which echoes how students revised their proposed hypotheses to make them more scientifically sound during the post-observation phase of the POE activities. In addition, Lati et al. (2012) mentioned that students' process skills, including stating hypotheses, could be improved if they had more chance to practice POE science inquiry.

In addition, qualitative findings including (a) the automated and real-time plotting function of graphs that helped students to externalize the effects of independent variables on dependent variables in the technology-enhanced POE activities in the FPOE; and (b) teacher clarification of student misinterpretation of the plotted graph in terms of scales and labels of axes in the FPOE activities, were the reasons for the improvement of the students' graphing and interpreting data skill in the FPOE approach. For instance, a student (FPOE-H-P-1) in the FPOE group stated that, "the change of light and the concentration of carbon dioxide [dependent variables] could be seen through the real-time plotted graph at different times." This finding is in agreement with Tho et al.'s (2015) study that a remote and computer-mediated experiment, similar to the technology-enhanced POE using mobile loggers, can provide precise data and clear graphs in real time to illustrate the results and visualize the variables being investigated. According to Tho and Yeung (2016), the time needed for routine procedure of plotting data could be saved and reallocated for more meaningful educational activities, such as interpreting results in their remote laboratory experiment. Similarly, time was saved for teachers to clarify students' misinterpretations about the graph in the FPOE in this current study. The limited chances to practice the skill of interpreting data, which is often regarded as time-consuming and omitted by instructors, could also be addressed (Lati et al., 2012). Moreover, the improvements of the stating hypotheses skill and the graphing and interpreting data skill might be attributed to the student-centered tutorial feature of both in-class (Dirks & Cunningham, 2006) and online interactive learning activities (Kramer et al. 2018), as well as the feature of computer-supported investigations (Geban et al., 1992) provided in the FPOE approach.

Lastly, the results from the paired sample *t*-tests suggested that students' overall ISPS was improved in both FPOE and TFC groups, while the results from the independent sample *t*-test suggested that the improvement of the students' overall ISPS of the students in the FPOE approach was significantly higher than that in the TFC approach. Together with the qualitative evidence illustrated, it is suggested that the FPOE approach, integrated with technology-enhanced POE activities, could be more effective to enhance students' overall ISPS than the TFC approach.

5.2.2 The Impacts of the Flipped Approaches (FPOE / TFC) on Students' SRL Abilities, LA, and SPS Compared with the TC (RQ2)

5.2.2.1 Self-Regulated Learning (SRL) Abilities

The results from the pairwise comparisons in the ANOVA of post-scores showed that only the FPOE approach was more effective at improving the students' average SRL ability and its several subscales, including goal-setting and time management, when compared with the TC approach.

These findings are consistent with Olakanmi and Gumbo's (2017) study, which found that students who participated in an SRL chemistry lesson had higher gain scores in average SRL ability (measured using a simplified MSLQ) compared with a conventional classroom. The SRL lesson, similar to the SRL strategy integrated into the FPOE pedagogy, involved Zimmerman's (2002) cyclical model of self-regulation, which allows students to set their learning goal (forethought phase); (b) monitor the tasks to meet their goals through different strategies and time management (performance phase); and (c) to self-evaluate and reflect on their learning processes (self-reflection phase). Therefore, students who participated in that type of SRL environment could benefit from improved goal-setting and time-management ability than those in conventional classrooms (Olakanmi & Gumbo, 2017). According to Lai and Hwang (2016), the monitoring mechanism in an FC integrated with an SRL strategy could engage students to empower their self-observation, determine the learning strategies to be applied, and be aware of their effectiveness, which may explain why students had better time-management abilities for their learning in the FPOE approach in this study.

On the other hand, Lai et al. (2018) suggested that computer-supported SRL science inquiry outperformed the improvement in students' time management compared with traditional science inquiry because students in the SRL environment focused more on their learning efficiency, which demanded students to have good time management during learning. This finding echoes the SRL strategy integrated in the technology-enhanced POE activities in the FPOE approach. In addition to the SRL strategy, the integration of technology-enhanced remote investigations with mobile loggers could also contribute to better time-management strategies among students in the FPOE approach, as previously discussed (Tho &Yeung, 2018).

Considering the advantages of the SRL and technology-enhanced POE activities mentioned above, as well as the benefits of flipped approaches discussed in the previous section (Section 5.2.2.1), it is not surprising to find that the average SRL ability of the students in the FPOE approach was significantly higher than that in the TC approach. This finding also concludes that, only the subject-specific FPOE approach rather than the conventional flipped classroom, could unleash the potential of FCs to improve students' SRL abilities in their science learning.

5.2.2.2 Learning Achievement (LA)

The results from the pairwise comparisons in the ANOVA of post-scores showed that the FPOE approach was more effective at improving the students' LA than the TC approach. This finding could be explained by the previously discussed advantages of the FC, including creating more time for in-class student-centered learning activities (Çetinkaya, 2017; Lo et al., 2018), having more chance to learn new knowledge (Lo et al., 2017), having more real-time feedback from teachers (Lo et al., 2017) and having a better management of cognitive load among students (Lo et al., 2018; Abeysekera & Dawson, 2015; Schultz et al. 2014). However, the results from the pairwise comparisons in the ANOVA of post-scores showed that the TFC approach was not more effective at improving the students' LA than the TC approach. This finding contradicts with several recent FC studies in secondary science education, which found that the conventional FC improves students' LA when comparing with its non-flipped counterparts (e.g., Atwa et al., 2016; Lo et al., 2018; Olakanmi, 2017; Schultz et al., 2014; Sezer, 2017; Yousefzadeh & Salimi, 2015). These findings suggest that, the subject specific FPOE approach rather than the conventional flipped classroom, could unleash the potential of FCs to improve students' LA in science learning.

5.2.2.3 Science Process Skills (SPS)

The results from the pairwise comparisons in the ANOVA of post-scores of the students' overall BSPS showed that neither the FPOE nor the TFC were more effective at improving the students' BSPS than the TC. Similarly, the results from the pairwise comparisons in the ANOVA of post-scores of the students' overall ISPS also showed that neither the FPOE nor the TFC were more effective at improving the students' ISPS than the TC. These results contradict Camiling's (2017) research, which found that elementary students who participated in an FC had significantly higher overall BSPS than those in a TC. Such finding might be due to the limitation of the research design, as comparisons could only be made based on the post-scores of the students' BAPS and ISPS. The acquisition of SPS could be incremental and step-by-step (Ong et al. 2015), meaning only comparing the students' final post-scores was ineffective for visualizing the difference in the improvements among students in different groups. Moreover, Tan, Yangco, and Que (2020) urged that the reliability of the instrument should also be considered regarding the non-significant findings of students' SPS, including inferring, predicting, controlling variables, and interpreting data, between an inquiry-based FC and a non-flipped inquiry-based TC. In fact, the reliability of the instruments for assessing the students' BSPS and ISPS was relatively low when compared with those assessing the students' SRL ability in this present study.

5.2.3 The Impacts of the Flipped Classroom Approaches in Terms of SRL Abilities, LA, and SPS on Students with Different Learning Abilities (RQ3 and RQ4)

5.2.3.1 Self-Regulated Learning (SRL) Abilities

Interestingly, the results from the independent sample *t*-tests of gain scores showed significant difference of environmental structuring ability among students with different learning abilities in the TFC approach. Specifically, the students with HL outperformed those with LL in the improvement of environmental structuring ability in the TFC approach. This finding is also supported by qualitative evidence. Some students with HL reported that they could find a quiet place for online learning in the TFC (n = 2 in HL, n = 0 in LL). For example, a student with HL (TFC-H-P-2) in the TFC group stated that, "I was keen on watching the online videos at home right after school in the afternoon before my parents returned home." The possible reason why the students with HL had higher environmental structuring ability is that they probably had good awareness of the self-regulated strategies, especially the importance of environmental structuring in online learning in the TFC. The absence of such a finding for the FPOE approach suggests that students, regardless of their learning ability, could learn and apply similar strategies in the FPOE approach as it required regular observations and monitoring during the online remote investigation (Tho & Yeung, 2015).

The finding also suggests that the FPOE approach is more advantageous for narrowing the diversity in terms of the enhancement of students' different subscales of SRL abilities. Together with the significant finding regarding the effectiveness of the FPOE approach at improving the students' SRL when compared with the TC (RQ2), it is likely to conclude that the integration of the FPOE approach could solve the problems of the relatively lower use of SRL strategies among Hong Kong secondary school students, and stimulate them to become intrinsically motivated to learn in a self-regulated way (Ho, 2004, 2014).

5.2.3.2 Learning Achievement (LA)

The results from the independent sample *t*-tests of gain scores showed that the students with HL outperformed those with LL in terms of the improvement of LA in both the FPOE and TFC approaches. Such quantitative results can be explained by the relatively higher account of the qualitative evidence in terms of (a) more time for activities, (b) learning of new knowledge, (c) real-time feedback from teachers, and (d) better management of cognitive load obtained from the students with HL in this study (FPOE: n = 10 in LL, n = 20 in HL; TFC: n = 5 in LL, n = 12 in HL). Considering these findings, it is not unreasonable to conclude that the higher achievers could better utilize the extra time obtained from the FCs for the student-centered science inquiries, in which they could engage in and achieve higher LA (Maxwell et al., 2015; Şimşek, & Kabapınar, 2010). Regarding the online pre-class learning, the findings are also in alignment with Francis's (2014) finding that higher achievers in a university had higher viewing frequency of the online videos than lower achievers, and thus, higher achievers received higher grades than lower achievers in the FC.

On the other hand, Nouri (2016) found that lower achievers had significantly more positive attitudes toward the FC, the use of video as a learning tool, and perceptions of increased learning and more effective learning when compared with higher achievers. It is, therefore, logical to hypothesize that lower achievers might have a higher gain of LA in flipped learning. However, the finding in this study, as in other FC studies (e.g., Van Sickle, 2016), rejects such hypothesis. One possible reason for this rejection is that higher achievers, despite having lower attitudes and perceptions toward FC, were still more driven by the examination-oriented school culture in terms of understanding and remembering than the lower achievers. This finding is also in line with Jong's (2017) conclusion that the non-significant difference in liberal studies performance between top academic-banding Hong Kong secondary students in the FC and TC was due to the ceiling effect, in which the independent variable (flipped or non-flipped) no longer affected the dependent variable (improvement of LA). Future research on Hong Kong students' attitudes and perceptions about flipped approaches and their correlations with LA is, thus, expected.

5.2.3.3 Science Process Skills (SPS)

The results from the independent sample *t*-tests of gain scores showed that the students with different learning abilities had significant differences regarding the improvements of stating hypotheses skills in the FPOE approach and designing investigation skill in the TFC approach.

Particularly, the students with HL outperformed those with LL in the improvement of stating hypotheses skill in the FPOE approach. The qualitative finding supports this result, with a higher number of identified codes regarding stating hypotheses among students with HL: (a) participation in the pre-observation stage of the POE activities helps to make tentative explanations; and (b) receiving feedback from the explanation stage of POE activities helps to propose reasonable hypotheses ($n = 1$ in LL, $n = 3$ in HL).

According to Burns et al. (1985), the skill of stating hypotheses requires students to state a testable hypothesis when provided with a description of the variables involved in an investigation. A testable hypothesis can be a tentative explanation for a phenomenon or an investigable question (Yip, 2007). In accordance with Yip (2007), Hong Kong science students, even at senior level, still often misunderstand the concept of hypotheses due to inadequate teaching about the processes of scientific inquiry, as most science teachers ask students to put forward a hypothesis for every investigation irrespective of its necessity. According to Ng and Yeung (2000), setting and testing hypotheses is regarded as a higher cognitive skill that senior science students still find challenging to manipulate. Fortunately, it is evident that the self-regulated and technology-enhanced POE activities offered in the FPOE could favor higher achievers to gain more chances and feedback regarding making testable tentative hypotheses, so that the misconceptions surrounding when and how to propose a hypothesis can be addressed.

Finally, the results from the independent sample *t*-tests of gain scores showed that the students with LL outperformed those with HL in the improvement of designing investigation skill in the TFC approach. The qualitative evidence also showed that more students with LL in the TFC group recognized the importance of the guidance they obtained from experimental videos for designing investigations in the follow-up lessons (n = 2 in LL, n = 1 in HL). As the skill of designing investigation demands students to select a suitable design for an investigation to test for a given hypothesis (Burns et al., 1985), it is possible that lower achievers could benefit more than high achievers from the utilization of didactic video lectures during out-of-class preparation in terms of designing investigation, particularly learning experimental procedures. This finding also echoes the benefit of the FC regarding relocating the preparation and revision work into video lectures, as HL might find these activities a waste of time if they were performed in a whole-class manner (Lo et al., 2018). Furthermore, this finding is absent in the FPOE group, suggesting that the extra technology-enhanced POE activities could help students, regardless of their learning abilities, to improve their designing investigation skill to a similar extent.

5.3 Limitations and Difficulties

This section highlights and describes the limitations of this research and the difficulties encountered during the FPOE and TFC interventions from student, teacher, and curriculum perspectives.

5.3.1 Limitations of the Research

There are several limitations in this research that are mainly attributed to the design of the research, the issues with data collection, and the teaching role of the researcher in this study.

First, this research involved a quasi-experiment, meaning that the randomization of the participants was not appliable, which limited the employment of statistical analysis involving covariates such as ANCOVA and MANCOVA (Fitzmaurice et al., 2004; Oakes & Feldman; 2001). Therefore, the statistical power of the quantitative findings might not be maximized.

Second, only post-scores of the OSLQ, BAPS, TIPS-II, and LAT were collected from the historical cohort due to the lack of ethical approval for data collection and a lack of time for the planning, development, translation, and administering of those surveys and tests at the very beginning of this research. Therefore, the absence of the pre-scores from the measurements restricted the use of independent sample *t*-tests on the students' gain scores for comparison between the FC (FPOE/TFC) and the TC.

Third, except for the assessment instruments developed from the PISA, there was no single well-established instrument to measure the students' science process skills and knowledge of science all at once. Due to the limited accessibility and adoption of the PISA instruments, as well as the possibility of the disclosure of the items of the PISA instruments to the public, this research employed a self-developed LAT and two well-established SPS tests, all of which are emphasized in the science curriculum, as suggested by the CDC (CDC, 2017b). Other SL components, such as attitudes toward science (OECD, 2016), the understanding of the nature of science, and society- and technology-related issues (Turiman, Omar, Daud, & Osman, 2012) were not investigated in this study.

Fourth, there was a lack of analysis from the observation of science lessons because some originally planned lesson observations could not be conducted due to a clash of teaching schedules between the researcher and other subject teachers. Another problem regarding the incomplete data collection was that one subject teacher felt uncomfortable being observed in the in-class inquiries during the FC interventions. Despite three lessons having already been observed and video-recorded, the absence of the data in one class of the current cohort limited the researcher's ability to make valid comparisons regarding student learning during in-class scientific inquiries among different FC groups. In addition, the lack of time to conduct enough lesson observations also hindered the researcher to further transform and quantify the qualitative data for interpretation.

Moreover, the information gathered from the survey and interviews was solely based on students' self-reporting, meaning trustworthiness is a possible issue. The assessment of students' SPS was merely based on the formative tests without the evaluation of students' inquiry-based competencies during the in-class scientific inquiries. The lack of resources, such as analytic software to trace students' SRL behaviors in the out-of-class learning platforms, was a result of this non-funded research. Furthermore, only 16 of the 124 students in the FCs were interviewed; thus, some opinions and voices of other students might not be explicitly revealed.

Researcher bias and reactivity due to the role of the researcher (Maxwell, 2013), who was also the science panel chairperson and subject teacher of the participants, should also be acknowledged. The researcher attempted to maintain a neutral attitude during the process of data collection to minimize his influence on the students' responses. Precautions were also made to avoid prejudice about the students' engagement and performance in the FCs because of the close relationship and halo effect, as well as bias during the development of the FC content due to the researcher's prior knowledge with the subject (e.g., focus mainly on biology-related topics).

Finally, although some measures, such as piloting interviews, multiple checking of the interview transcripts, and comparing the interview data with the codes, were carried out (see Section 3.5), there remains a lack of validation of the coding process from other independent and experienced researchers. Therefore, it is necessary for the researcher to ensure the inter-rater's reliability regarding the findings when the results are published in the future.

Overall, the limitations discussed might restrict the generalization of the research findings to other age groups, levels, and school types.

5.3.2 Difficulties Implementing the Flipped Classroom Approaches

5.3.2.1. Student Perspective

According to the qualitative evidence, there were several student-related and operation-related challenges (Betihavas et al., 2016) that prevented the FC approaches from fully unleashing their potential benefits regarding student science learning. First, some students in the TFC group struggled to familiarize themselves with the flipped learning at the very beginning stage (C-S-F) (*n* = 2). Such familiarization includes how to access instructional videos, experimental videos, and learning materials such as PowerPoint and animations, as well as how to perform and complete the online quizzes. Although a workshop on the use of LMS in flipped learning was provided for the students at the beginning of the academic year, problems continued to be raised during the initial stage. This issue echoes another difficulty that students would be lacking in rapid out-of-class support from teachers, especially when facing technical problems (C-S-S) (*n* =1). Several students reported an operation-related technical problem involving not being able to access the videos and online streaming in the LMS (C-O-A) owing to living outside Hong Kong (*n* = 1). Most frequently, students reported that the learning in the flipped approaches, regardless of whether FPOE or TFC, involved too heavy workload (C-S-D) (*n* = 6). Such frustration might possibility hinder them from actively participating in the flipped learning during the interventions. Finally, there was also a lack of communication and cooperative learning opportunities between students during the POE activities (see Section 5.2.1.3.1), limiting the enrichment of their science learning journey.

5.3.2.2 Teacher Perspective

The science teachers (*n* =3) participating in this research generally found the extra time gained from flipping the lessons useful. They were also motivated to conduct scientific inquiries during the in-class learning because some of these activities had been co-planned and implemented in the previous academic year. In addition, they were also very engaged in the three-hour workshop about the use of FC offered by the EDB before the interventions. However, most subject teachers were not experienced to address student problems during the online learning in the FCs, especially in the technology-enhanced FPOE approach, which requires technical knowledge regarding the maintenance of the mobile loggers and the use of software applications to conduct the POE activities successfully. This obstacle is in line with Tho and Yeung's (2018) finding that the responsibility of teachers in a remote laboratory experiment is enormous, and the teacher, but not the students, needs to prepare greatly to achieve successful experimental results. This responsibility was taken by the researcher with support offered by the principal supervisor in this study, suggesting a first-order barrier that demands time and energy, and a second-order barrier that demands technical confidence (Wang, 2017) were existed among the other science teachers. Owing to these barriers, valuable feedback and the possibility of co-planning among the science teachers for future POE investigations using mobile loggers in the FPOE might also be limited.

5.3.2.3 Curriculum Perspective

There was a limited number of technology-enhanced POE activities using mobile loggers (especially in Unit 8: Electricity) planned and integrated in the FPOE approach because not all content and epidemic knowledge in every topic of the curriculum was suitable for integration. It was also challenging to plan and design extra and suitable scientific inquiries coherent with the pre-class POE activities. Undeniably, such coherence was vital in the TFC as students could learn by remembering and understanding from instructional videos before participating in more difficult cognitive activities such as scientific inquiries (Sams & Bergmann, 2013). However, the students might already have experienced a higher level of learning, including applying, analyzing, and evaluating in the online technology-enhanced POE activities; thus, extra and newly developed scientific inquiries were also required for the in-class sessions in the FPOE. Finally, integrating flipped learning in this research might have hindered other learning foci of the subject, such as the use of English as the medium of instruction (MOI) and project-based learning activities in the school-based science curriculum.

5.4 Recommendations for Future Research and Practice

In response to the limitations of the research methodology and the difficulties mentioned above, several recommendations for future research and practice are suggested.

5.4.1 Recommendations for Future Research

First, future research should collect more forms of evidence, such as lesson observations, analyses of student works, behavioral logs in the LMS, and teacher interviews, to obtain an in-depth and wider exploration of how students learn in out-of-class online conditions and in-class scientific inquiries in FCs (Abeysekera & Dawson, 2015; Giannakos et al., 2014).

Second, pre-tests of SRL, LA, and SPS on students in the historical TC should also be administered so that quantitative data of the students' initial scores can be collected and more precise comparisons between flipped pedagogical approaches and conventional classrooms can be made.

Third, a more in-depth quantitative study could be conducted to find out which element of the FPOE, the incorporation of the POE activities or the use of mobile loggers for mobile investigation, is more critical for improving students' SRL abilities, LA, and SPS.

Fourth, students' attitudes and perceptions toward FCs and toward the science subject, which is regarded as a component of SL in PISA 2015 (OECD, 2016), have not been addressed in this study. Therefore, they should be further investigated. A study of the relationships between students' attitudes and SRL abilities, LA, and SPS could also be made. Furthermore, student motivation, which is one of the vital factors leading to the success of a flipped course (Liu, Ripley, & Lee, 2016), is worth thoroughly evaluating in the FPOE approach.

Finally, the correlation between the SRL abilities, LA, and SPS in the flipped approaches (FPOE and TFC) and the moderation effect of the flipped approaches on student learning outcomes should be investigated. A study on how students with different categorizations of SRL level (high/low) improve their LA and SPS is also recommended to explore the vital effect of SRL strategies on student science learning in the FC (Sletten, 2017).

5.4.2 Recommendations for Future Practice

Primarily, a more interactive online environment should be constructed regarding the need for students to inquire about the technical problems they may encounter during the FPOE and TFC interventions. Such an interactive platform should also enable cooperative POE activities in which students can share their predictions with the group, form a consensus prediction to discuss with other groups, and obtain feedback and guidance from the teacher for subsequent explanations to facilitate the integrated acquisition of conceptual and procedural knowledge in science (Cinici & Demir, 2013). This type of interactive online environment can either be constructed in the LMS or on other platforms, such as WhatsApp, and can be conducted regularly as seamless tutorials in Zoom, which is an online and real-time video-conferencing application, for the needs of the science teachers in different classes.

Second, other means of knowledge delivery, such as videos, quizzes, and worksheets, and recorded streaming stored on a CD/DVD/USB device (Sezer, 2017) can be prepared for students with accessing problems.

Third, it is necessary to provide capacity building (Wang, 2017) for science teachers in terms of pedagogical training about flipped learning and technical training on the use of mobile investigations (in FPOEs) prior to interventions. Such professional development should not only familiarize teachers with new technologies and pedagogies, but also help them to justify why a paradigm shift to FC pedagogy is necessary (Wang, 2017).

Finally, future development and integration of technology-enhanced POE activities into more science topics and a holistic mapping of the FPOE into the current school-based science curriculum are recommended.

Chapter 6: Conclusion

Summary of Literature Research and Identified Research Gaps

The performance of scientific literacy among Hong Kong secondary school students has been progressively falling in the last three PISA cohorts since 2012, suggesting that a paradigm shift on the integration of innovative pedagogy is necessary. In line with the latest science curriculum in Hong Kong, which emphasizes the enhancement of students' SRL abilities, LA, and SPS (CDC, 2017a; 2017b), a flipped learning approach has been recommended due to its advantage of creating more class time for student-centered activities by relocating didactic lectures to online videos before the lesson (CDC, 2017a, EDB, 2014). In the last decade, the number of studies on the integration of FCs in different educational disciplines grew dramatically, but those with appropriate theoretical and pedagogical foundations to unleash FC impacts in secondary science education remain limited. Methods on how to flip science lessons, as well as the efficacy of FC on SRL abilities, LA, and SPS on students with different abilities in secondary science education, are still undetermined by a lack of empirical research. Therefore, a science-specific, self-regulated, and technology-enhanced modified FC that integrated a POE strategy (FPOE) was designed and implemented in this study. The effectiveness of the FPOE approach on SRL abilities, LA, and SPS among secondary science students with different learning abilities was examined and compared with the traditional flipped learning approach (TFC) and non-flipped traditional classroom (TC).

List of Research Questions

RQ1: Can the FPOE improve students' SRL abilities, LA, and SPS in comparison with the TFC?

RQ2: Are there differences in the improvements of students' SRL abilities, LA, and SPS among different pedagogical approaches (FPOE vs. TFC vs. TC)? If yes, which is the most effective?

RQ3: Do student learning abilities (lower and higher) affect the improvements of their SRL abilities, LA, and SPS in different flipped pedagogical approaches (FPOE and TFC)?

RQ4: How and to what extent do the FPOE and TFC help students with different learning abilities to improve their SRL abilities, LA, and SPS?

Executive Summary of Research Approach, Sampling, and Implementation

This study employed a sequential, explanatory, mixed-methods design (Creswell, 2009; Creswell & Plano Clark, 2007). This design included a non-equivalent control group pre-test–post-test design of a quasi-experiment (Campbell et al., 1963) comprising an experimental FPOE group (n =63) and a control TFC group (n =61) for seven months in Form 2 (Grade 8) science between 2018 and 2019 to address the RQ1, RQ3, and RQ4. Furthermore, a historical control group of a non-flipped TC (n =*63*) from the previous academic year (2017–2018) was included to address the RQ2. Both the FPOE and TFC approaches provided instructional videos and quizzes for pre-class preparation and scientific inquiries for in-class student-centered learning. Only the FPOE approach included an additional four video-supported POE activities and two real-time POE activities using mobile loggers. The TC was also conducted with the same amount and type of scientific inquiries in face-to-face traditional lessons.

Quantitative data were collected and analyzed initially to examine the difference between the flipped pedagogical approaches (FPOE/TFC) and the TC in terms of the improvements of the students' SRL abilities, LA, and SPS. The differences in the improvements between students with different learning abilities in the FPOE and TFC were also investigated. Subsequently, qualitative evidence from student interviews was collected and analyzed to explain the quantitative findings. The sampling of interviewees was primarily based on their collective performance in LA, SRL abilities, and SPS after flipped learning interventions. Finally, sixteen students were selected, with an equal proportion of genders, flipped learning approaches (FPOE/TFC), and learning abilities (higher/lower).

Concluding Statements

The research findings confirm that the FPOE was more effective at improving the students' time-management ability, overall BSPS and its subscale of measurement skill, overall ISPS and its subscales of stating hypotheses, and graphing and interpreting data skills when compared with the TFC approach attribute to the features of self-regulated and technology-enhanced POE strategies embedded in the FPOE approach. Furthermore, both the FPOE and TFC approaches were effective at improving the students' LA, overall ISPS and its subscales of identifying variables, operational defining, and designing investigation skills because of the benefits of the flipped approach, such as reducing the students' cognitive load through online lecturing and creating more time for tailoring during the in-class scientific inquiries (addressing RQ1 and RQ4). When compared with the TC, the results confirm that only the FPOE was more effective at improving the students' average SRL ability and its subscales of goal-setting and time-management abilities, as well as the students' LA (addressing RQ2).

Moreover, the results confirm that the FPOE approach enhanced students' SRL abilities regardless of their learning ability. The findings also validate that the technology-enhanced POE activities in the FPOE were advantageous for higher achievers to improve their skill of stating hypotheses, which has generally been misinterpreted by senior science students in Hong Kong (Yip, 2007). Moreover, the results also confirm that both the FPOE and TFC approaches were beneficial for higher achievers to enhance their LA as they were more exam-driven than lower achievers, and thus, had better utilizations of their online and in-class learning regarding the understanding and remembering of content knowledge offered by the flipped approaches. Finally, the results validate that lower achievers had better improvement than higher achievers regarding their designing investigation skill in the TFC because of the direct illustrations of experimental procedures provided in the online videos (addressing RQ3 and RQ4).

6.1 Personal Reflection

Science teachers in secondary schools often "see themselves as just teachers rather than as teachers and scientists" (Johnson, 2002, p. 4). This study undoubtedly bridged this gap by providing many opportunities for the researcher, who is also a science teacher in a Hong Kong secondary school, to be involved in *doing* science, which includes preparing scientific investigations with innovative approaches, and *teaching* science, which includes following-up students' online learning and facilitating their in-class scientific inquiries in the FPOE. This experience also enriched the researcher's knowledge about the most up-to-date technology (e.g., Arduino) used for designing mobile laboratory experiments in science education (Yeung et al., 2015; Yeung et al., 2019).

Throughout this research, the researcher needed to collaborate consistently with the principal supervisor and his research team at the EdUHK. This type of partnership between a secondary school and a university was vital and enabled the researcher to learn appropriate theory that was beneficial for the accurate implementation of the intervention. This study also encouraged the researcher to evaluate the existing research findings and trends about FC in secondary science education through the peer-review process with the principal supervisor.

Moreover, this study strengthened the researcher's belief that frontline teachers should be reflective practitioners to question and study the effectiveness of their teaching practices, as well as being enthusiastic about collaborating with colleagues to enhance their professionalism (Wright, 2015). As another role of the researcher was being the science panel chairperson of the school, this study offered him the chance to evaluate and refine the current school-based science curriculum to meet the subject's future needs.

Finally, conducting the research not only helped the researcher to investigate the students' SRL abilities in the flipped approaches, but also promoted a sense of self-regulated learning for the researcher because successive planning, monitoring, and self-evaluating strategies were necessary throughout the design and implementation of the FPOE and TFC pedagogies in this research.

6.2 Educational Implications

This study confirms the hypothesis that the flipped learning approach, particularly the FPOE approach, is an effective pedagogy to improve science students' SRL, LA, and SPS. This finding implies that Hong Kong secondary students, who are often regarded as having relatively low SRL ability in learning science when compared with other East Asian students (Ho, 2004), can play a proactive role in their own initiatives and strategies in their learning process through the FPOE pedagogical approach. In the FPOE, students were responsible for preparing for in-class scientific inquiries by watching videos, finishing follow-up quizzes, and participating in the POE activities. Such preparation, which is considered a passive event conventionally, can only be accomplished by students with the utilization of their SRL strategies (Sletten, 2017).

Furthermore, the effectiveness of the FPOE approach regarding the improvement of students' SPS suggests that the FPOE could be helpful for promoting self-efficacy in scientific inquiry among Hong Kong junior secondary students, who are often regarded as lacking self-efficacy when formulating inquiry questions, proposing hypotheses, analyzing and presenting data with graphs and tables, drawing appropriate conclusions, identifying sources of errors, and explaining anomalous results (Cheung, 2007). The findings of the positive impacts of the FPOE approach on students' LA and SPS also imply that the FPOE could be an advantageous strategy to improve the SL of secondary school students in Hong Kong. The capability of the FPOE approach to reduce the differences of SRL abilities between lower and higher achievers also implies that the approach is valuable for improving secondary school students' SRL in a whole-class manner, regardless of their prior learning ability. The impact of the FPOE approach on higher achievers in terms of their improvement of setting and testing hypotheses, which is often regarded as a higher cognitive skill (Ng & Yeung, 2000), might also suggest that integrating the FPOE approach could be a useful strategy to satisfy the needs of Hong Kong gifted students and, thus, develop them into talented scientists (Lau & Lam, 2017).

Regarding the implications for the teaching of science from teachers' perspectives, flipping a science class can provide more time for in-class, student-centered learning, in which (a) higher-ordered learning activities such as scientific inquiries and collaborative problem-solving activities can be conducted; (b) student learning progress can be tailored based on individual needs; and (c) student misconceptions about science can be easily identified during teacher-student interactions. Consequently, student learning motivation and interests in science can also be enhanced. In addition, the successful implementation of the FPOE in this study suggests that such a modified flipped approach would be feasible for engaging students to learn science during special circumstances, such as the COVID-19 epidemic, when schools have been suspended (Fung, 2020). The positive impacts of the FPOE approach might also be attainable in other science-related subjects, such as senior-level physics, chemistry, biology, and STEM education in Hong Kong.

From the perspective of science education, the research finding implies that the synergistical combination of the theoretical framework of an SRL theory and the pedagogical approach of technology-enhanced POE activities is effective for grounding a flipped science course in secondary schools in Hong Kong. This finding provides valuable empirical evidence to the growing body of literature specifying the use of FCs in secondary science education. The empirical evidence obtained in this study also testifies to the feasibility of implementing a science-specific FC that emphasizes the curriculum needs of SRL (CDC, 2017a), LA and SPS (CDC, 2017b) in secondary schools in Hong Kong. Finally, the challenges and difficulties encountered in this study might act as essential references and provide usable knowledge for the future design and implementation of FCs in other educational disciplines.

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Appendix 1. Recommendations for the design of the FC following Spector's six pillar (Lo, 2018)

Pillars	Recommendations
Communication	1. Introduce the FC approach to students and obtain parental consent **Students and parents consent obtained before the FC interventions** 2. Use cognitive theory of multimedia learning to inform the production of instructional videos **Videos were created within 5 minutes. Subsections and summaries were also provided**
Interaction	3. Create a discussion forum for online interactions **Discussion forum was created in the LMS / Discussions with the teachers were also made via WhatsApp** 4. Provide online quizzes on video lectures with computerized feedback **Videos and quizzes with auto/computerized feedback were provided**
Environment	5. Provide human resources and technical resources to support FC practices **Panel head (the researcher) and one subject teacher were in responsible for the coordination of the implementation of FC. Supports from laboratory technician, and the research team from the principal supervisor were also received** 6. Adopt a school-/faculty-wide approach to FC practices **The use of FC for SRL was introduced as the science subject major concern in the year plan of the school**

Culture	7. Cultivate a classroom culture for learner-centered instruction **Inquiry-based learning was implemented in science lessons**
Instruction	8. Utilize established models as the framework for FC design **Established frameworks including SCLT, SDT, CLT, SRL and 5-E instructional model were adopted**
Learning	9. Provide optimally challenging learning tasks with instructor's guidance **Challenging tasks in the FPOE / inquiry-based learning were provided** 10. Use peer-assisted learning approaches during class **Collaborative approach of inquiry-based learning was implemented during the in-class learning**

Note. Adapted from "Grounding the flipped classroom approach in the foundations of educational technology" by C. K. Lo, 2018, *Educational Technology Research and Development, 66,* p. 799.

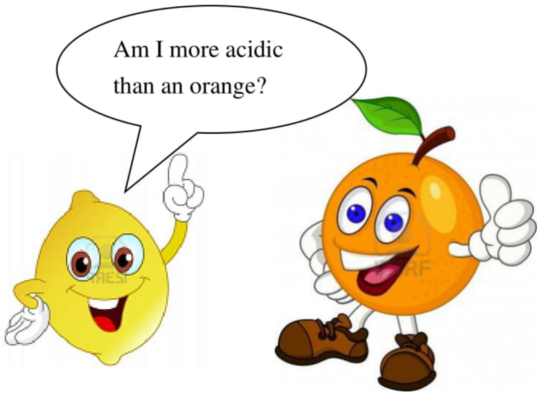
Appendix 2. Lesson worksheets of an example of scientific inquiry

18-19/S2/Sci/Acids & alkalis: neutralization/P1

Kau Yan College
2018 – 2019 S. 2 Science
Unit 9 Common Acids & Alkalis -- Neutralization

Class: S2 ___ Name: ____________________ ( ) Date: _____

Different acids have different acidity. Some acids are more acidic than others. Which one is more acidic and which one is less acidic?



Task

1. You are provided with 3 solutions, ***X, Y*** and ***Z***. Design and carry out an experiment to arrange the acidities of the 3 solutions provided ***in ascending order*** **without using pH paper / universal indicator directly**.
2. Write a report for your investigation.

Apparatus & Materials

1.	10ml measuring cylinder	1	7.	Universal indicator	1 bottle
2.	Conical flask	1	8.	Dilute sodium hydroxide solution	1 bottle
3.	Syringe	3	9.	Solution X	
4.	White tile	1	10.	Solution Y	
5.	pH colour chart	1	11.	Solution Z	
6.	50ml beaker	3	12	Labels	some

Title

Investigation on the comparison of the acidities of solutions X, Y and Z.

Hint for your design

1. What is the name of the reaction when we add acid to sodium hydroxide solution?
2. If the solution is more acidic, do we need to use smaller or greater amount of that solution to neutralize the sodium hydroxide solution?
3. Which solution will you put into the conical flask?
4. Which solution will you put into the syringe?

Variables

Identify the variables in your experiment.

Independent variable (variable to be changed)	Dependent variable (variable to be compared & measured)	Controlled variables (variables to be kept constant)

Procedure

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Results

Title: ____

Discussion

1. What is the pH value of the resulting solution when the sodium hydroxide is just neutralized?

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2. What is the relationship between the amount of solution used to neutralize the sodium hydroxide solution and acidity of that solution?

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3. Suggest ***ONE*** possible source of error in your investigation.

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4. Suggest ***ONE*** improvement for your investigation.

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Conclusion

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Appendix 3. Online Self-Regulated Learning Questionnaire (OSLQ)

Kau Yan College 2018-2019 Science
Self-regulated Learning Questionnaire 自主學習問卷

Class: ___________ (   ) Date: _________

1: Strongly disagree 非常不同意 2: disagree 不同意 3: neutral 中立 4: agree 同意 5: Strongly agree 非常同意	1	2	3	4	5
Goal setting 訂立目標:					
1. I set standards for my assignments in online science learning. 我為網上科學學習的課業訂立標準。	○	○	○	○	○
2. I set short-term (daily or weekly) goals as well as long-term goals (monthly or for the term).我設定了短期（每日或每週）目標以及長期目標（每月或每學期）。	○	○	○	○	○
3. I keep a high standard for my online science learning. 我在網上科學學習中保持高的水準。	○	○	○	○	○
4. I set goals to help me manage studying time for my online science learning. 我訂立目標來幫助自己管理在網上學習科學的時間。	○	○	○	○	○
5. I don't compromise the quality of my work because it is online. 我不會因為上網而影響我的學習質素。	○	○	○	○	○
Environment structuring 學習環境:					
6. I choose the location where I study to avoid too much distraction. 我選擇合適的學習地方以避免分心。	○	○	○	○	○
7. I find a comfortable place to study. 我會找一個舒適的地方進行學習。	○	○	○	○	○
8. I know where I can study most efficiently for online science learning. 我知道在哪裡能使我最有效地在網上學習科學。	○	○	○	○	○
9. I choose a time with few distractions for studying for my online science learning. 我選擇了一個沒有分心的時間來在網上學習科學。	○	○	○	○	○
Task strategies 任務策略:					
10. I try to take more thorough notes for my online learning because notes are even more important for learning online than in a regular classroom. 我嘗試為網上學習提供更全面的筆記，因為筆記對於網上學習比在課室更重要。	○	○	○	○	○
11. I read aloud instructional materials posted online to fight against distractions. 我大聲朗讀網上教學材料，以防止分心。	○	○	○	○	○
12. I prepare my questions before joining in the chat room and discussion online. 我會先準備好問題，然後在網上聊天室和討論區發問。	○	○	○	○	○
13. I work extra problems in my online science learning in addition to the assigned ones to master the course content. 除了指定的課程內容之外，我還在我的網上科學學習中解決額外的問題。	○	○	○	○	○

1: Strongly disagree 非常不同意 2: disagree 不同意 3: neutral 中立 4: agree 同意 5: Strongly agree 非常同意	1	2	3	4	5
Time management 時間管理:					
14. I allocate extra studying time for my online science learning because I know it is time-demanding. 我為網上科學學習分配了額外的學習時間，因為我知道這對很費時。	○	○	○	○	○
15. I try to schedule the same time everyday or every week to study for my online science learning, and I observe the schedule. 我嘗試為每天或每周安排同一時間在網上學習科學，並觀察有關安排。	○	○	○	○	○
16. Although we don't have science classes everyday, I still try to distribute my studying time evenly across days. 雖然我們未必每天都有科學課，但我仍然嘗試將我的學習科學的時間平均分配。	○	○	○	○	○
Help seeking 尋求協助:					
17. I find someone who is knowledgeable in course content so that I can consult with him or her when I need help. 我找到一個對課程內容有深入了解的人，以便在有需要的時候我可以諮詢他/她。	○	○	○	○	○
18. I share my problems with my classmates online so we know what we are struggling with and how to solve our problems. 我在網上與同學分享我所遇到的問題，所以我們知道大家的困難及解決方法。	○	○	○	○	○
19. If needed, I try to meet my classmates face-to-face. 如有需要，我會嘗試與我的同學面對面交流。	○	○	○	○	○
20. I am persistent in getting help from the teacher out-of-class online. 我堅持不懈地在網上尋求老師的幫助。	○	○	○	○	○
Self-evaluation 自我評估:					
21. I summarize my learning in the online science course to examine my understanding of what I have learned. 我總結了我在網上科學課程中的學習情況，以檢視對所學內容的理解。	○	○	○	○	○
22. I ask myself a lot of questions about the course material when studying for the online science course. 在進行網上學習時，我問自己很多關於課程資料的問題。	○	○	○	○	○
23. I communicate with my classmates to find out how I am doing in my online science course. 我與同學們溝通，了解自己在網上科學學習中的表現。	○	○	○	○	○
24. I communicate with my classmates to find out what I am learning that is different from what they are learning. 我與同學交流，了解自己所學的會否與他們所學的有所不同。	○	○	○	○	○

Appendix 4. Test of Basic Process Skills in Science (BAPS)

KAU YAN COLLEGE
2018 – 2019
S.2 Science
Basic Science Process Skills Test

Date: ______________
Time Allowed: 30 minutes Level: S2
Max. Mark: 36

INSTRUCTIONS

1. There are 36 **Multiple Choice Questions** in this test. Attempt **ALL** questions.
2. Answers should be marked on the Multiple-Choice Answer Sheet.
3. The diagrams in this paper are not necessarily drawn to scale.
4. Use a pencil to answer the questions.

救恩書院
2018 – 2019 年度
中二科學
基本科學過程技能測試

日期：______________ 級別: S2
測驗時間：30 分鐘
總分：36 分

考生須知:

1. 本卷共有 72 題選擇題。全部試題均須回答。
2. 答案應填畫在多項答題紙上。
3. 本卷中的圖表不一定是按比例繪製的。
4. 考生應使用鉛筆回答問題。

Basic Process Skills Test

1. Last week Eric and his friends went fishing. They each caught one fish. Who caught the longest fish?

A. Eric B. Karen C. Jason D. Jenny

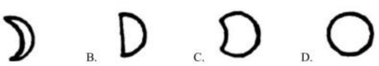
2. Which statement best describes the sounds you wound hear if you were in this picture?

A. I would hear a bird singing, butterfly flying, and dog barking.
B. I would hear a man walking, bird singing, and the sun shining.
C. I would hear a bird singing, dog barking, and man walking.
D. I would hear a dog barking, bird singing, the sun shining.

3. Bill and Mack went to summer camp. At night they looked at the moon and noticed these changes:

Day 2 Day 4 Day 6 Day 8

What will the moon look like next?



A. B. C. D.

基本科學過程技能測試

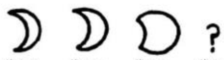
1. 上週埃里克和他的朋友去釣魚了。他們每人抓到一條魚，誰抓到的魚是最長？

A.埃里克 B.凱倫 C.傑森 D.珍妮

2. 如果你在這張照片中，哪個陳述最能描述你聽到的聲音？

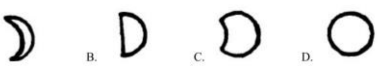
A. 我會聽到鳥兒唱歌，蝴蝶飛舞，還有狗叫聲。
B. 我會聽到一個人走路，鳥兒在唱歌，陽光燦爛。
C. 我會聽到鳥兒在唱歌，狗的叫聲，還有人走路。
D. 我會聽到一隻狗叫，鳥兒在唱歌，陽光燦爛。

3. 比爾和麥克去了夏令營。晚上他們看著月亮，發現了這些變化：



第 2 天 第 4 天 第 6 天 第 8 天

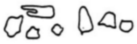
接下來第 8 天的月亮是什麼樣的？

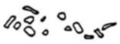


A. B. C. D.

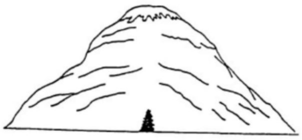
4. A scientist found this ancient bone in a cave.

Which group of bones should it be in?

A. 
B. 

C. 
D. 

5. Use the tree as a measure. How many trees high is the mountain?



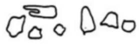
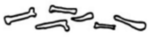
A. 3 B. 4 C. 5 D. 6

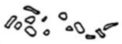
6. Last weekend 8 of your fish died. Two are still alive. That is the <u>best explanation</u> for what happened?

A. The fish will get better.
B. The fish got lonely.
C. The fish have a disease,
D. Two fish died Sunday,

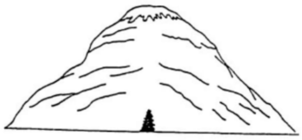
4. 一位科學家在洞穴中發現了這塊古老的骨頭。

它應該是以下哪一組骨頭？

A. 
B. 

C. 
D. 

5. 使用樹作為度量單位，山有多少棵樹那麼高？



A. 3 B. 4 C. 5 D. 6

6. 上週末你的 8 條魚死了，兩個還活著。對於發生的事情，最好的解釋是？

A. 魚會變好
B. 魚變得孤獨
C. 魚患了病
D. 週日有兩條魚死亡

7. Rick and Carol collected a basket of shells. They wanted to sort the shells into 2 groups. What would be the best way to sort these?

A. By shape
B. By age
C. By the number of lines
D. By where they were found

8. Kelley was playing in the path. She spotted an animal in the bushes. Which sentence tells you the most about what the animal <u>looked like</u>?

A. It was brown and scared.
B. It was tired and cold.
C. It was small with four legs.
D. It looked like a mouse with a short tail.

9. Jim found this leaf on his way to school.

What is your <u>best guess</u> about what happened to the leaf?

A. It has a rough edge,
B. A bug was eating it.
C. It has a stem.
D. A boy picked it.

7. 瑞克和卡羅爾收集了一籃子貝殼，他們想把貝殼分成兩組，什麼是對這些進行分類的最佳方式？

A. 按貝殼形狀
B. 按貝殼年齡
C. 按貝殼表面上的線條的數目
D. 按貝殼被發現的地方

8. 凱利在路上玩耍， 她在灌木叢中發現了一隻動物。以下哪句最能告訴你那是什麼動物？

A. 牠是棕色的及牠很害怕。
B. 牠感到疲倦和寒冷。
C. 牠很細小，並共有四條腿。
D. 牠看起來像一隻尾巴很短的老鼠。

9. 吉姆在去學校的路上發現了這片葉子。

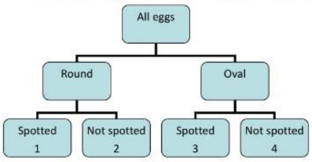
你猜測葉子發生了什麼事？

A. 它有一個粗糙的邊緣。
B. 一隻蟲正在吃它。
C. 它有一個莖。
D. 它是被一個男孩撿起來的。

10. Debbie is watching a nest of baby birds. The babies are very big. They do not have enough room in the nest. Use this information. What do you think will happen?

A. The birds will stay healthy.
B. The birds will learn to fly and leave the nest.
C. The birds are ready to fly.
D. The mother bird has stopped feeding her tobies.

11. Bob found some eggs in the woods. This picture shows how he put them into groups.



What box would you place this egg in?

A. 1 B. 2 C. 3 D. 4

12. You have a plant in your garden. It has grown 3 centimeters (cm) in 3 days. Use this fact. Guess what will most likely happen to the plant in the next 3 days.

A. The plant will stop growing.
B. The plant will grow 3 more centimeters (cm).
C. The plant grows 1 centimeters (cm) per day.
D. The plant grows because of the sunlight.

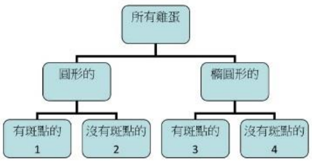
13. Which island has something missing?

A. B. C. D.

10. 黛比正在看一窩幼鳥。嬰兒非常大，他們沒有足夠的空間。你認為將會發生什麼事？

A. 鳥類會保持健康。
B. 這些鳥會學會飛行並離開巢穴。
C. 鳥兒準備飛翔了。
D. 母鳥已停止餵飼幼鳥。

11. 鮑勃在樹林裡發現了一些雞蛋。 這張照片展示了他如何將它們分組。



你要把這個蛋放在什麼盒子裡？

A. 1 B. 2 C. 3 D. 4

12. 你的花園裡有一棵綠色植物，它在 3 天內生長了 3 厘米（cm）。 使用這個事實，猜猜未來 3 天那棵綠色植物最有可能發生的事情。

A. 綠色植物將停止生長。
B. 綠色植物將生長多 3 厘米（cm）。
C. 綠色植物每天生長 1 厘米（cm）。
D. 綠色植物因陽光而生長。

13. 哪個島嶼缺少了一些東西？

A. B. C. D.

14. Denis wanted to build a snail fort. She went into the woods looking for sticks. She found one like this.

stick: 

stone: 

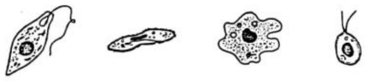
She broke the stick into 2 equal pieces. How many stones long would each piece be?

A. 2 B. 4 C. 6 D. 8

15. Nick was watching a squirrel in a tree. What could he tell about the squirrel just from looking at it?

A. The squirrel was brown and had a long, bushy tail.
B. The squirrel was 2 years old.
C. The squirrel was looking for food for its babies.
D. The squirrel lived in the park.

16. Mary brought a jar of pond water to class. She looked at the water under a microscope. She saw these creatures.



Which trait do all of these creatures have?

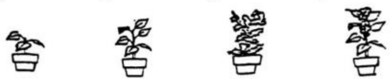
A. Hairs B. Cigar shape C. A large dark spot D. Tail

17. Lauren planted some seeds in a pot. This is how the plant looked

1 week 2 weeks 3 weeks

What will there plants probably look like after 4 weeks?

A. B. C. D.



14. 丹尼斯想要建造一個蝸牛堡壘。 她走進樹林尋找木棒，發現了以下木棒。

棒： 

石： 

她把木棒分成兩塊相等的木條，每塊木條的長度佔多少塊石頭？

A. 2 B. 4 C. 6 D. 8

15. 尼克在樹上看著一隻松鼠，他能從看著松鼠知道什麼呢？

A. 松鼠是棕色的，尾巴長而濃密。
B. 這隻松鼠已經 2 歲了。
C. 松鼠正為其嬰兒尋找食物。
D. 松鼠住在公園裡。

16. 瑪麗帶了一罐池塘水去上課。 她在顯微鏡下觀察， 她看到了以下這些生物。

以上所有這些生物都具有哪些特質？

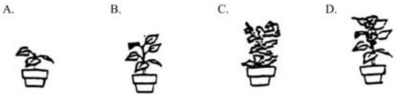
A. 毛髮 B. 雪茄形狀 C. 一個大的黑點 D. 尾巴

17. 勞倫在鍋裡種了一些種子，以下就是植物的樣子。

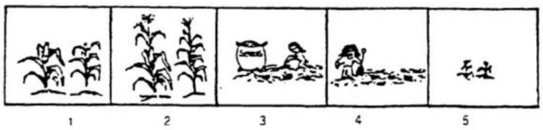
1 週 2 週 3 週

4 週後植物可能會是什麼樣子？

A. B. C. D.



18. Rose grew corn in her garden. She wants to show what happened with pictures. Help her by choosing the correct order for these pictures.

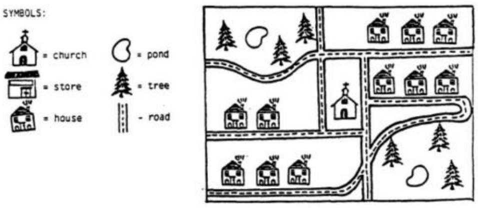


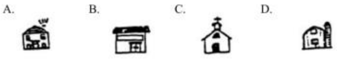
A. 3, 5, 4, 1, 2
B. 4, 5, 3, 2, 1
C. 3, 4, 1, 5, 2
D. 4, 3, 5, 1, 2

19. Jessica found an old tree deep in the woods. She wanted to tell her friends how to get there. What would be the <u>most important</u> thing for them to know?

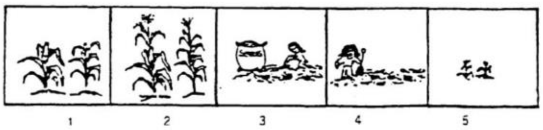
A. The direction and distance she went.
B. How many fields she passed along the way.
C. What the tree looked like.
D. What time she got there.

20. Leah found this old map in her grandmother's attic. She wanted to add a store to the map. What symbol should she use?





18. 羅斯在她的花園種植玉米。她想展示圖片發生的事情，通過為這些圖片選擇正確的順序來幫助她。

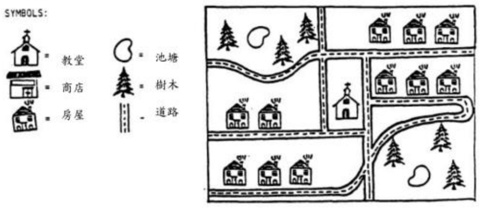


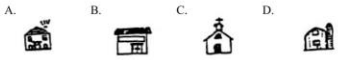
A. 3, 5, 4, 1, 2
B. 4, 5, 3, 2, 1
C. 3, 4, 1, 5, 2
D. 4, 3, 5, 1, 2

19. 傑西亞在樹林深處發現了一棵老樹。她想告訴她的朋友如何到達那裡。對他們來說最重要知道的是什麼？

A. 她所在地方的方向和距離。
B. 她沿途經過了多少個田地。
C. 樹的樣子。
D. 她什麼時候到那兒。

20. 利亞在她祖母的閣樓裡發現了這張舊地圖。 她想在地圖上添加一個商店。 她應該使用什麼符號？





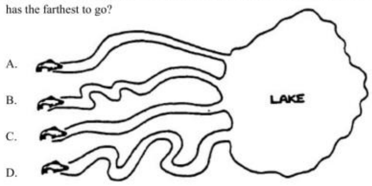
21. What symbol appears most often on Leah's map? (See question 20)

A. House
B. Church
C. Store
D. Tree

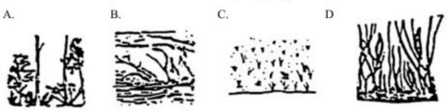
22. What is the best description of Leah's old map? (See question 20)

A. It is a town with a church, a factory, and 2 ponds.
B. It is a city with many churches and many roads.
C. It is a city with lots of trees, stores, and schools,
D. It is a town with 2 ponds, many houses, and a church.

23. Four streams are connected to a lake. The fish in each stream want to get to the lake. Which fish has the farthest to go?



24. A lion was hunting for his dinner. A zebra saw the lion and knew he had to hide. What would be the best hiding place for this zebra?



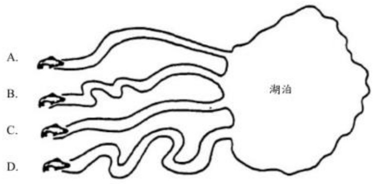
21. 利亞的地圖上最常出現的符號是什麼？（見問題 20）

A. 一個房屋
B. 教堂
C. 商店
D. 樹木

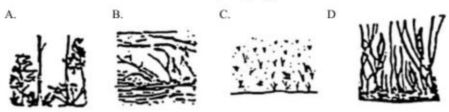
22. 以下哪段最能描述利亞的舊地圖？（見問題 20）

A. 這是一個有教堂，工廠和 2 個池塘的小鎮。
B. 這是一座擁有眾多教堂和眾多道路的城市。
C. 這是一個有很多樹木，商店和學校的城市，
D. 這是一個有 2 個池塘，許多房屋和教堂的小鎮。

23. 四條溪流與湖泊相連，每條溪流中的魚都想游去湖泊。以下哪條魚距離湖泊最遠？



24. 一隻獅子正在尋找他的晚餐。斑馬看見獅子，知道他必須藏起來。以下哪裡是斑馬最好的藏身之處？



25. Joseph and Linda did a project in science class. They recorded the temperature of water each minute. This chart below shows what they found.

TIME	TEMPERATURE
1 minute	18°C
2 minutes	22°C
3 minutes	25°C
4 minutes	29°C
5 minutes	__ C

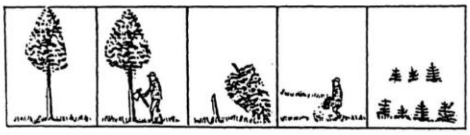
What do you think the temperature of the water will be after five minutes?

A. 26°C B. 29°C C. 32°C D. 35°C

26. Use the chart from the question above. What is the best explanation for what happened?

A. The water was on a hot stove.
D. The water was in a cooler.
C. The water was sitting on a desk.
D. The water was outside under a tree.

27. What story des this set of pictures tell?



A. The man cut down a large tree, He used it for firewood.
B. Lightning killed a large tree. The man planted some smaller trees.
C. A man cut off some branches from a large tree. He planted some smaller trees.
D. The man cut down a large tree. He planted some smaller trees.

25. 約瑟夫和琳達在科學課上做了一個專題研習，他們每分鐘記錄一次水的溫度。下面的圖表記錄了內容。

時間	溫度
1 分鐘	18°C
2 分鐘	22°C
3 分鐘	25°C
4 分鐘	29°C
5 分鐘	__ °C.

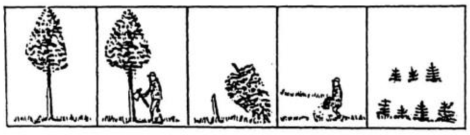
您認為五分鐘後水的溫度是多少？

A. 26°C B. 29°C C. 32°C D. 35°C

26. 使用上述問題的圖表，發生了事的最佳解釋是什麼？

A. 水在熱爐上。
D. 水在涼爽的地方。。
C. 水放在桌子上。
D. 水放在樹下面。

27. 這組照片講的是什麼故事？

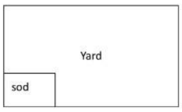


A. 一名男子砍了一棵大樹，用它做木柴。
B. 雷擊中一棵大樹，而之後那男子種了一些小樹。
C. 一名男子從一棵大樹上砍下一些樹枝，之後並種了一些小樹。
D. 一名男人砍倒了一棵大樹。 之後並種了一些小樹。

28. You went on a school field trip. You saw these 2 sets of animal tracks. Look at these tracks. What guess can you make about what happened?

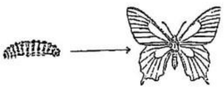
A. The animals eat at night.
B. The tracks of one set are larger than the tracks of the other set.
C. The 2 animals had a fight.
D. The tracks were made by the same kind of animal.

29. Heather wanted to plant some sod. Her yard was 3 meters (m) long and 4 meters (m) wide. How many pieces of sod will she need to cover her yard? Use the picture to find out.



A. 7 B. 10 C. 12 D. 14

30. The picture below shows a caterpillar that grew into a butterfly. What can you tell about what happened just from these prictures?



A. When the caterpillar grew up, it no longer ate leaves.
B. When the caterpillar grew up, it could not fly very fast.
C. When the caterpillar grew up, it had 6 legs.
D. When the caterpillar grew up, it got wings.

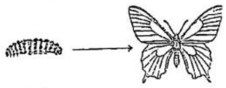
28. 你去學校實地考察，並看過這兩組動物的足跡。從這些足跡，您對發生的事情有什麼猜測？

A. 動物在晚上進食。
B. 一組動物的足跡大於另外的一組。
C. 兩隻動物發生了爭執。
D. 足跡是由同一種動物形成。

29. 希瑟想種一些草皮。 她的院子長 3 米（m），寬 4 米（m）。 她需要多少塊草皮覆蓋她的院子？ 使用圖片找出答案。

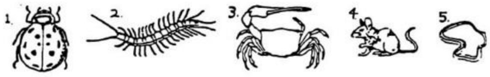
A. 7 B. 10 C. 12 D. 14

30. 下圖顯示了一隻由毛蟲成長變成的蝴蝶。你能描述發生了什麼事情？



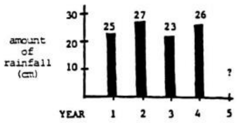
A. 當毛蟲長大後，它不再吃葉子了。
B. 毛蟲長大後，飛得很快。
C. 當毛蟲長大後，它有 6 條腿。
D. 當毛蟲長大後，它有翅膀。

31. Cathy observed these creatures in science class. She wants to put them in order by the number of legs they have. What is the correct order?



A. 5, 1, 3, 4, 2
B. 5, 4, 1, 3, 2
C. 2, 3, 4, 1, 5
D. 2, 1, 3, 4, 5

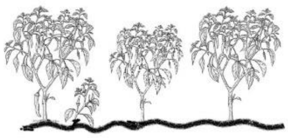
32. Tom is studying weather. This chart shows how much rain fell in his town for four years.



What is the best guess about how much rain will fall next year?

A. 17 cm B. 21 cm C. 25 cm D. 29 cm

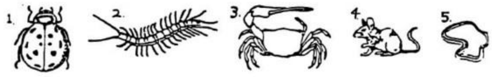
33. Mr. Lee planted 5 pepper plants in his backyard. After 6 weeks, his pepper plants looked like this.



What does this tell you about Mr. Lee's pepper plants?

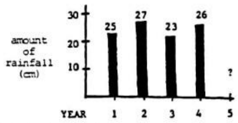
A. All of his plants were the same size.
B. All of his pepper plants had produced peppers.
C. There were bugs on his pepper plants.
D. His pepper plants were not getting enough water.

31. 凱茜在科學課上觀察了這些生物。她希望通過他們擁有的腿數將它們整理好。 以下哪個是正確的順序？



A. 5, 1, 3, 4, 2
B. 5, 4, 1, 3, 2
C. 2, 3, 4, 1, 5
D. 2, 1, 3, 4, 5

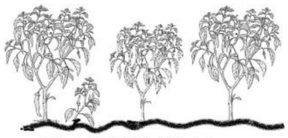
32. 湯姆正在研究天氣，這張圖表顯示了他的城鎮連續四年的降雨量。



猜測明年的降雨量是多少？

A. 17 cm B. 21 cm C. 25 cm D. 29 cm

33. 李老師在他的後院種了 5 株辣椒植物。 6 週後，他的辣椒植物看起來像這樣。



以下哪句正確描述李老師的辣椒植物。

A. 他種的所有植物都有相同的大小。
B. 他種的所有辣椒植物都生產了辣椒。
C. 他的辣椒植物上有蟲子。
D. 他的辣椒植物沒有得到足夠的水。

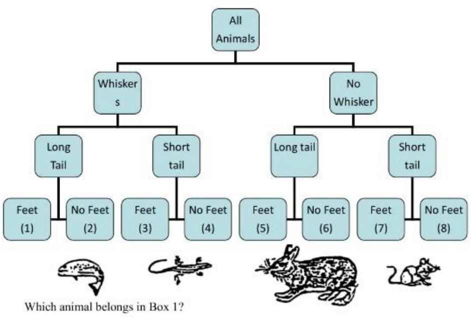
34. Last week, Russ went looking for snail creatures. This chart shows where he looked and what he found.

	LOCATION	SPIDERS	SOWBUGS	WORMS
1.	under rocks	8	3	2
2.	in a pile of leaves	4	6	3
3.	under an old log	2	3	7
4.	in the grass	7	9	5

Where is the best place to find worms?

A. under rocks
B. under a pile of leaves
C. under an old log
D. in the grass

35. Colleen and her father went to the pet store. They classified the animals they saw this way.



Which animal belongs in Box 1?

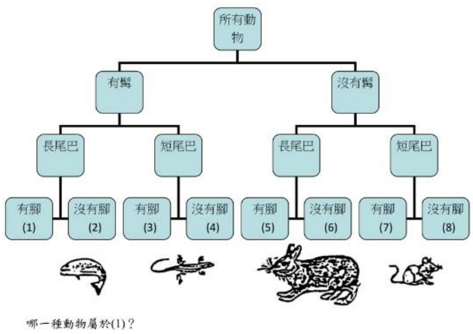
A. Fish
B. Lizard
C. Rabbit
D. mouse

34. 上週拉斯去尋找蝸牛生物，該圖表顯示了他看到和發現的。

位置	蜘蛛	潮蟲	蠕蟲
在岩石下	8	3	2
在一堆葉子裡	4	6	3
在舊木頭下	2	3	7
在草地上	7	9	5

找到蠕蟲的最佳地點在哪裡？
A. 在岩石下
B. 在一堆葉子裡
C. 在舊木頭下
D. 在草地上

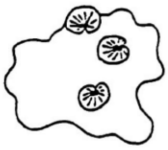
35. 科琳和她的父親去了寵物店，將並他們看到的動物分類。



哪一種動物屬於(1)？

A. 魚
B. 蜥蜴
C. 兔子
D. 老鼠

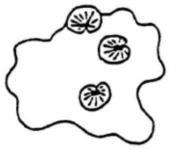
36. Vicky drew a map o f a pond in her yard. The objects in the pond are lily pads. About how many lily pads would it take to cover the whole pond?



A. 10 B. 18 C. 24 D. 36

The End

36. 玉萍畫了一張池塘地圖。池塘裡的種了睡蓮葉。整個池塘需要多少睡蓮覆蓋？



A. 10 B. 18 C. 24 D. 36

全卷完

Appendix 5. Test for Integrated Process Skills II (TIPS-II)

2018-2019/S2/Science/ P.1/26

KAU YAN COLLEGE
2018 – 2019
S.2 Science
Integrated Science Process Skills Test

Date: ____________
Time Allowed: 35 minutes Class: S2
Max. Mark: 36

INSTRUCTIONS

1. There are **36 Multiple Choice Questions** in this test. Attempt **ALL** questions.
2. All answers should be marked on the Multiple-Choice Answer Sheet.
3. The diagrams in this paper are not necessarily drawn to scale.
4. Use a pencil to answer the questions.

2018-2019/S2/Science/ P.2/26

救恩書院
2018 - 2019 年度
中二科學
綜合科學過程技能測試

日期：____________
測驗時間：35 分鐘 班別: S2
總分：36 分

考生須知:

1. 本卷共有 36 題選擇題。全部試題均須回答。
2. 答案應填畫在多項答題紙上。
3. 本卷中的圖表不一定是按比例繪製的。
4. 考生應使用鉛筆回答問題。

2018-2019/S2/Science/ P.3/26

1. A football coach thinks his team loses because his players lack strength. He decides to study factors that influence strength. Which of the following variables might the coach study to see if it affects the strength of the players?

   A. Amount of vitamins taken each day.
   B. Amount of lifting exercises done each day.
   C. Amount of time spending exercises.
   D. All of the above.

2. A study of the efficiency of car is conducted. The hypothesis tested is that a gasoline additive will increase the car efficiency. Five identical cars each receive the same amount of gasoline but different amounts of Additive A. The cars travel along the same road until they run out of gasoline. The distance each car travels is recorded. How is the car efficiency measured in this study?

   A. The time each car runs out of gasoline.
   B. The distance each car travels.
   C. The amount of gasoline used.
   D. The amount of Additive A used.

3. An car manufacturer wants to make cars cheaper to operate. They are studying variables that may affect the distance that the cars travel. Which variable is likely to affect the car can travel?

   A. The weight of the car.
   B. The volume of the engine.
   C. The colour of the car.
   D. Both A and B.

4. A class is studying the speed of objects as they fall to the earth. They design an investigation where bags of gravel weighing different amounts will be dropped from the same height. In their investigation, which of the following is the hypothesis they would test about the speed of objects falling to earth?

   A. An object will fall faster when it is dropped further.
   B. The higher an object is in the air the faster it will fall.
   C. The larger the pieces of gravel in a bag the faster it will fall.
   D. The heavier an object the faster it will fall to the ground.

2018-2019/S2/Science/ P.4/26

1. 一名足球教練認為他的球隊因為球員缺乏力量而輸球，他決定測試一些影響力量的因素。教練可以研究以下哪些變量以查看是否可以它影響球員的力量？

   A. 每天服用維生素的份量。
   B. 每天的舉重練習量。
   C. 鍛煉的時間。
   D. 以上全部。

2. 在一項測試汽車效率的研究裡，測試的假設是汽油添加劑會增加汽車的效率。五輛相同的汽車每輛都收到相同數量的汽油，但不同數量的添加劑 A。汽車沿著相同的道路行駛直到它們用完汽油，並記錄每輛車行駛的距離。在這項研究中如何測量汽車的效率？

   A. 每輛輛汽車消耗所有汽油的時間。
   B. 每輛車行駛的距離。
   C. 汽車使用的汽油量。
   D. 汽車使用的添加劑 A 份量。

3. 一家汽車製造商希望使汽車運行更便宜。他們正在研究可能會影響汽車行駛距離的變項。以下哪個變項很可能影響汽車的行駛距離？

   A. 汽車的重量。
   B. 發動機的體積。
   C. 汽車的顏色。
   D. A 和 B.

4. 一個班級正在研究物體跌落地球時的速度。他們設計了一個探究，其中重量不同的碎石袋將從相同的高度落下。在他們的探究中，以下哪一項是他們將測試物體下降速度的假設？

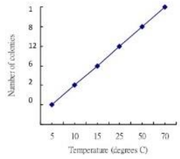
   A. 一個物體進一步掉落時會下降的速度得更快。
   B. 物體在空氣中越高，其下降的速度越快。
   C. 一個袋子裡的碎石越大，其下降的速度越快。
   D. 物體越重，它下降到地面的速度就越快。

5. A student in a science class studied the effect of temperature on the growth of bacteria. The student obtained the following data:

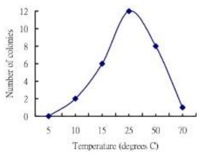
Temperature of the growth chamber (°C)	Number of bacterial colonies
5	0
10	2
15	6
20	12
50	8
70	1

Which graph correctly represents the data from the experiment?

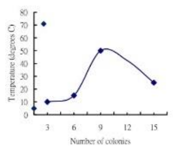
A.



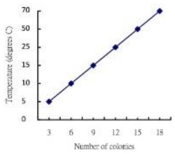
B.



C.



D.



6. A police inspector is concerned about reducing the speed of vehicle. He thinks several factors may affect the speed of the vehicle. Which of the following is a hypothesis he could test about how fast people drive?

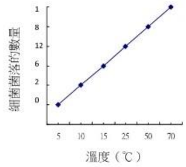
A. The younger the drivers, the faster they are likely to drive.
B. The larger the vehicle involved in an accident, the less likely people are to get hurt.
C. The more policemen on patrol, the fewer the number of vehicle accidents.
D. The older the vehicle, the more accidents they are likely to be in.

5. 一位科學班的學生研究了溫度對細菌生長的影響。學生獲得的數據如下：

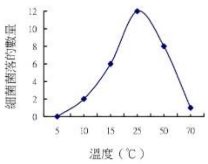
生長室的溫度 (°C)	細菌菌落的數量
5	0
10	2
15	6
20	12
50	8
70	1

以下哪個圖表正確地表示實驗的數據？

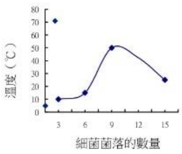
A.



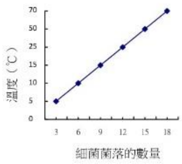
B.



C.



D.



6. 警察擔心車輛的速度。他認為幾個因素可能會影響車輛的速度。以下哪一項是能測試駕駛速度的假設？

A. 司機越年輕，他們可能駕駛得越快。
B. 事故中涉及的車輛越大，受傷的可能性就越小。
C. 巡邏的警察越多，車禍的次數就越少。
D. 車輛越老，他們可能會遇到的事故就越多。

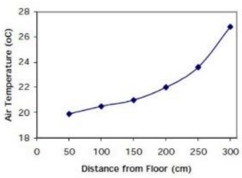
7. A science class is studying the effect of width of wheel on ease of rolling. The class puts wide wheels onto a small cart and lets it roll down an inclined ramp and then across the floor. The investigation is repeated using the same cart but this time fitted with narrow wheels.
How could the class measure ease of rolling?

A. Measure the total distance the cart travels.
B. Measure the angle of the inclined ramp.
C. Measure the width of each of the two sets of wheels.
D. Measure the weight of each of the carts.

8. A farmer wonders how he can increase the amount of corn he grows. He plans to study factors that affect the amount of corn produced. Which of these hypotheses could he test?

A. The greater the amount of fertilizer, the larger the amount of corn produced.
B. The greater the amount of corn, the larger the profits for the year.
C. As the amount of rainfall increases, the more effective the fertilizer.
D. As the amount of corn produced increases, the cost of production increases.

9. A study is done on the air temperature in a room at different distances from the floor. The graph of the data is shown below.



How are the variables related?

A. As distance from the floor increases, air temperature decreases.
B. As distance from the floor increases, air temperature increases.
C. An increase in air temperature means a decrease in distance from the floor.
D. The distance from the floor is not related to air temperature increases.

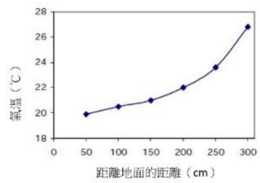
7. 一個科學班正在研究車輪寬度對滾動容易度的影響。該班將寬輪放在一個小推車上，然後讓它沿傾斜的斜坡滾下，然後穿過地板。使用相同的小推車重複調查，但這次配有窄的車輪。該科學班怎麼能測量滾動的容易程度？

A. 測量小推車行走的總距離。
B. 測量斜坡傾斜的角度。
C. 測量兩組輪子的寬度。
D. 測量每個推車的重量。

8. 一位農民想知道如何增加他種植的玉米數量，他計劃研究影響玉米產量的因素。他應該測試以下哪些假設？

A. 肥料量越多，玉米產量越多。
B. 玉米數量越多，今年的利潤就越大。
C. 隨著降雨量的增加，肥料越有效。
D. 隨著玉米產量的增加，生產成本增加。

9. 對房間內與地板不同距離的空氣溫度進行了研究。數據圖如下所示。



變項之間有什麼關係？

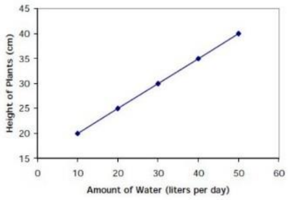
A. 隨著與地板的距離增加，空氣溫度降低。
B. 隨著與地板的距離增加，空氣溫度升高。
C. 空氣溫度的升高意味著距離地板的距離減小。
D. 與地板的距離與氣溫升高無關。

10. Jim thinks that the more air pressure in a basketball, the higher it will bounce. To investigate this hypothesis he collects several basketballs and an air pump with a pressure gauge.
How should Jim test his hypothesis?

A. Bounce basketballs with different amounts of force from the same height.
B. Bounce basketballs having different air pressures from the same height.
C. Bounce basketballs having the same air pressure at different angles from the floor.
D. Bounce basketballs having the same amount of air pressure from different heights.

11. A study is being done on the amount of water needed to grow plants. Five small garden plots are given different amounts of water. After two months the height of the plants is measured. The data are shown on the graph.

What is the relationship between the variables?



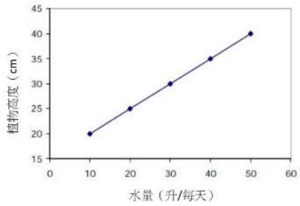
A. Increasing the amount of water increases the height of the plants.
B. Increasing the height of the plants increases the amount of water.
C. Decreasing the amount of water increases the height of the plants.
D. Decreasing the height of the plants decreases the amount of water.

10. 吉姆認為籃球的氣壓越大，它就反彈得越高。為了研究這個假設，他收集了幾個籃球和一個連接壓力計的氣泵。吉姆應該如何測試他的假設？

A. 從相同的高度下用不同的力量反彈籃球。
B. 從相同的高度下反彈不同氣壓的籃球。
C. 從與地板不同的角度下反彈具有相同氣壓的籃球。
D. 從相同的高度下反彈相同氣壓的籃球。

11. 一項研究正在研究種植植物所需的水量。五個小花園給予不同的水量，並在兩個月後，測量植物的高度。數據顯示在圖表上。

變項之間有什麼關係？



A. 增加水量會增加植物的高度。
B. 增加植物的高度會增加水量。
C. 減少水量會增加植物的高度。
D. 降低植物的高度會減少水量。

Direction: Questions 12 to 15 refer to the scenario below.
Marie wondered if the earth and oceans are heated equally by sunlight. She decided to conduct an investigation. She filled a bucket with dirt and another bucket of the same size with water. She placed them so each bucket received the same amount of sunlight. The temperature in each was measured every hour from 8:00 a.m. to 6:00 p.m.

12. Which hypothesis was being tested?

A. The greater the amount of sunlight, the warmer the soil and water become.
B. The longer the soil and water are in the sun, the warmer they become.
C. Different types of materials are warmed differently by the sun.
D. Different amounts of sunlight are received at different times of the day.

13. Which of these variables is controlled in Marie's study?

A. Kind of water placed in the bucket.
B. Temperature of the water and soil.
C. Type of material placed in the buckets.
D. Amount of time each bucket put under the sun.

14. What was the dependent variable in Marie's study?

A. Kind of water placed in the bucket.
B. Temperature of the water and soil.
C. Type of material placed in the buckets.
D. Amount of time each bucket is in the sun.

15. What was the independent variable in Marie's study?

A. Kind of water placed in the bucket.
B. Temperature of the water and soil.
C. Type of material placed in the buckets.
D. Amount of time each bucket is in the sun.

方向：問題 12 至 15 參考以下的情景。
瑪麗想知道陸地和海洋是否會被陽光平等地加熱。她決定進行一項探究，在一個桶裡裝滿了泥土，並在一個同樣大小的桶裡裝滿了水。她放好兩個桶並使每個桶都接受相同分量的陽光。她從早上 8 點到下午 6 點每一小時測量每個桶裡的溫度。

12. 探究測試以下哪種假設？

A. 日照量越大，土壤和水變得越暖。
B. 土壤和水在陽光下的時間越長，它們變得越溫暖。
C. 不同類型的材料被太陽加熱致不同程度。
D. 在一天中的不同時間會接收到不同分量的陽光。

13. 在瑪麗的研究中，哪些變項受到控制？

A. 放置在桶裡的水。
B. 水和土壤的溫度。
C. 放置在桶裡的材料。
D. 每個桶放在陽光下的時間。

14. 瑪麗研究中的應變項是什麼？

A. 放置在桶裡的水。
B. 水和土壤的溫度。
C. 放置在桶裡的材料。
D. 每個桶放在陽光下的時間。

15. 瑪麗研究中的獨立變項是什麼？

A. 放置在桶裡的水。
B. 水和土壤的溫度。
C. 放置在桶裡的材料。
D. 每個桶放在陽光下的時間。

16. Susan is studying food production in bean plants. She measures food production by the amount of starch produced. She notes that she can change the amount of light, the amount of carbon dioxide, and the amount of water that plants receive. What is a testable hypothesis that Susan could study in this investigation?
   A. The more carbon dioxide a bean plant gets, the more starch it produces.
   B. The more starch a bean plant produces, the more light it needs.
   C. The more water a bean plant gets, the more carbon dioxide it needs.
   D. The more light a bean plant receives, the more carbon dioxide it will produce.

Direction: Questions 17 to 20 refer to the scenario below.

Joe wanted to find out if the temperature of water affected the amount of sugar that would dissolve in it. He put 50 mL of water into each of four identical jars. He changed the temperatures of the jars of water until he had one at 0°C, one at 50°C, one at 75°C, and one at 95°C. He then dissolved as much sugar as he could in each jar by stirring.

17. What is the hypothesis being tested?
   A. The greater the amount of stirring, the greater the amount of sugar dissolved.
   B. The greater the amount of sugar dissolved, the sweeter the liquid.
   C. The higher the temperature, the greater the amount of sugar dissolved.
   D. The greater the amount of water used, the higher the temperature.

18. What is a controlled variable in Joe's study?
   A. Amount of sugar dissolved in each jar.
   B. Amount of water placed in each jar.
   C. Number of jars used to hold water.
   D. The temperature of the water.

19. What is the dependent variable in Joe's study?
   A. Amount of sugar dissolved in each jar.
   B. Amount of water placed in each jar.
   C. Number of jars used to hold water.
   D. The temperature of the water.

20. What is the independent variable in Joe's study?
   A. Amount of sugar dissolved in each jar.
   B. Amount of water placed in each jar.
   C. Number of jars used to hold water.
   D. The temperature of the water.

16. 蘇珊正在研究豆類植物的糧食生產。她通過產生的澱粉來測量食物的產量。她指出，她可以改變光量，二氧化碳量和植物吸收的水份量。這次研究中，什麼是可測試的假設？
   A. 豆類植物獲得的二氧化碳越多，產生的澱粉就越多。
   B. 豆類植物產生的澱粉越多，它所需的光就越多。
   C. 豆類植物獲得的水越多，它所需的二氧化碳就越多。
   D. 豆類植物接收的光越多，它產生的二氧化碳就越多。

方向：問題 17 至 20 參考下面的情景。

阿祖想知道水的溫度是否會影響糖溶解的份量。他在四個相同的罐子裡放入 50 毫升水。他改變了罐子的溫度:一個在 0°C，一個在 50°C，一個在 75°C，一個在 95°C。然後他通過攪拌盡可能將最多的糖溶解在每個罐子的水裡。

17. 實驗測試的假設是什麼？
   A. 攪拌量越大，溶解於水的糖量越多。
   B. 溶解於水的糖量越多，溶液越甜。
   C. 溫度越高，溶解於水的糖量越多。
   D. 使用的水量越多，溫度越高。

18. 在阿祖的研究中，控制變項是什麼？
   A. 每個罐子裡可溶解於水的糖量。
   B. 放入每個罐子裡的水量。
   C. 用於盛水的罐子數量。
   D. 水的溫度。

19. 在阿祖的研究中，應變項是什麼？
   A. 每個罐子裡可溶解於水的糖量。
   B. 放入每個罐子裡的水量。
   C. 用於盛水的罐子數量。
   D. 水的溫度。

20. 在阿祖的研究中，獨立變項是什麼？
   A. 每個罐子裡可溶解於水的糖量。
   B. 放入每個罐子裡的水量。
   C. 用於盛水的罐子數量。
   D. 水的溫度。

21. A greenhouse manager wants to speed up the production of tomato plants to meet the demands of anxious gardeners. She plants tomato seeds in several trays. Her hypothesis is that the more moisture seeds receive the faster they sprout. How can she test her hypothesis?
   A. Count the number of days it takes for seeds receiving different amounts of water to sprout.
   B. Measure the height of the tomato plants a day after each watering.
   C. Measure the amount of water used by plants in different trays.
   D. Count the number of tomato seeds placed in each of the trays.

22. A gardener notices that his squash plants are being attacked by aphids. He needs to get rid of the aphids. His brother tells him that "Aphid-Away" powder is the best insecticide to use. The county agent says "Squash-Saver" spray works the best. The gardener selects six squash plants and applies the powder to three and the spray to three. A week later he counts the number of live aphids on each of the plants.
   How is the effectiveness of the insecticides measured in this study?
   A. Measuring the amount of spray or powder used.
   B. Determining the condition of the plants after spraying or dusting.
   C. Weighing the squash each plant produces.
   D. Counting the number of aphids remaining on the plants.

23. Lisa wants to measure the amount of heat energy a flame will produce in a certain amount of time. A Bunsen burner will be used to heat a beaker containing 1 liter of cold water for ten minutes. How will Lisa measure the amount of heat energy produced by the flame?
   A. Note the change in water temperature after ten minutes.
   B. Measure the volume of water after ten minutes.
   C. Measure the temperature of the flame after ten minutes.
   D. Calculate the time it takes for the liter of water to boil.

24. Mark is studying the effect of temperature on the rate that oil flows. His hypothesis is that as the temperature of the oil increases it flows faster.
   How could he test this hypothesis?
   A. Heat oil to different temperatures and weigh it after it flows out of the can.
   B. Observe the speed at which oil at different temperatures flows down a smooth surface.
   C. Let oil flow down smooth surfaces at different angles and observe its speed.
   D. Measure the time it takes for oil at different thicknesses to pour out of the can

21. 溫室管理員希望加快番茄植物的生產，以滿足焦慮的園丁的需求。她在幾個托盤中種植番茄種子。她的假設是種子接受的水分越多，發芽的速度就越快。她怎樣能測試她的假設？
   A. 計算番茄種子接受不同水量而發芽所需要的日數。
   B. 測量番茄植物在每次澆水後一天的高度。
   C. 測量番茄植物在不同托盤中使用的水量。
   D. 計算每個托盤中放置的番茄種子的數量。

22. 園丁注意到他的南瓜植物受到蚜蟲的襲擊。他需要擺脫蚜蟲。他的兄弟告訴他，"Aphid-Away" 粉末是最好的殺蟲劑。該地方代理則說 "Squash-Saver" 噴霧效果最佳。園丁選擇六株南瓜植物並將粉末施用於三株，噴霧施用至另外三棵。一周後，他計算了每株植物上活蚜蟲的數量。在這項研究中如何測量殺蟲劑的有效性？
   A. 測量所用噴霧或粉末的量。
   B. 噴灑或撒粉後測量植物的狀況。
   C. 測量每株植物產生的南瓜的重量。
   D. 計算植物上剩餘的蚜蟲數量。

23. 麗莎想要測量火焰在一定時間內產生的熱能量。她將使用本生燈並將含有 1 升冷水的燒杯加熱 10 分鐘。麗莎將如何測量火焰產生的熱量？
   A. 測量水溫在十分鐘後的變化。
   B. 測在十分鐘後水的容量。
   C. 測量十分鐘後火焰的溫度。
   D. 計算一升水煮沸所需的時間。

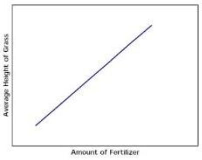
24. 馬克正在研究溫度對石油流動速度的影響。他的假設是: 隨著石油溫度的升高，它的流動速度更快。他如何測試這個假設呢？
   A. 將油加熱到不同溫度，並在從罐中流出後稱重。
   B. 觀察不同溫度下油沿光滑表面流動的速度。
   C. 讓油以不同角度沿光滑表面流下並觀察其速度。
   D. 測量不同厚度的油從罐中倒出所需的時間

25. A researcher is testing a new fertilizer. Five small fields of the same size are used. Each field receives a different amount of fertilizer. One month later the average height of the grass in each plot is measured. The measurements are shown in the table below.

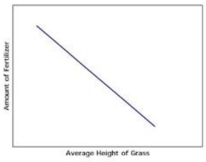
Amount of Fertilizer (kg)	Average Height of Grass (cm)
10	7
30	10
50	12
80	14
100	12

Which graph represents the data in the table?

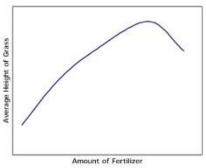
A.



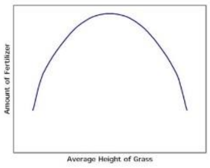
B.



C.



D.

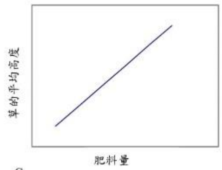


25. 一位研究人員正在測試一種新的肥料。他使用五個相同大小的田圃。每個田圃都接收不同數量的肥料。 一個月後，研究人員測量每個田圃中草的平均高度。測量結果如下表所示。

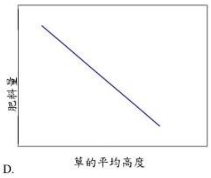
肥料量（kg）	草的平均高度（cm）
10	7
30	10
50	12
80	14
100	12

哪個圖表代表表中的數據？

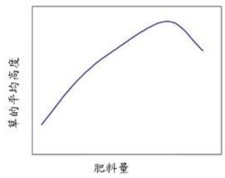
A.



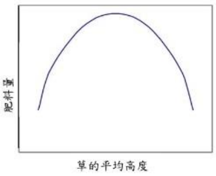
B.



C.



D.



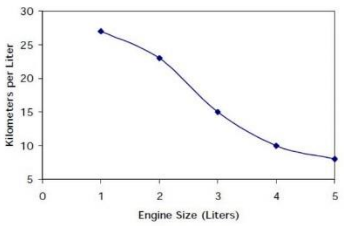
26. A biologist tests this hypothesis: the greater the amount of vitamins given to rats, the faster they will grow. How can the biologist measure how fast rats will grow?

A. Measure the speed of the rats.
B. Measure the amount of exercise the rats receive.
C. Weigh the rats every day.
D. Weigh the amount of vitamins the rats will eat.

27. Some students are considering variables that might affect the time it takes sugar to dissolve in water. They identify the temperature of the water, the amount of sugar and the amount of water as variables to consider. What is a hypothesis the students could test about the time it takes for sugar to dissolve in water?

A. The larger the amount of sugar the more water required to dissolve it.
B. The colder the water the faster it has to be stirred to dissolve.
C. The warmer the water the more sugar that will dissolve.
D. The warmer the water the more time it takes the sugar to dissolve.

28. A consumer group measures the kilometers per liter cars gets with different size engines. The results are as follows:



Which of the following describes the relationship between the variables?

A. The larger the engine, the more kilometers per liter the car gets.
B. The fewer kilometers per liter the car gets, the smaller the engine.
C. The smaller the engine, the more kilometers per liter the car gets.
D. The more kilometers per liter for a car, the larger the engine.

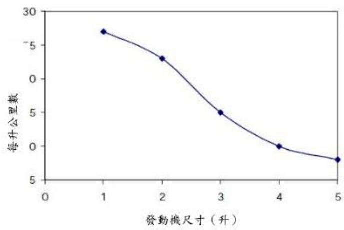
26. 一位生物學家測試了以下假設：給予大鼠的維生素含量越多，牠們的生長速度就越快。生物學家如何測量大鼠的生長速度？

A. 測量大鼠的速度。
B. 測量大鼠接受的運動量。
C. 每天測量大鼠的重量。
D. 測量大鼠食用的維生素量。

27. 一些學生正在考慮能影響糖溶解在水中的時間的變項。他們將水的溫度，糖和水的份量確定為需要考慮的變項。以下哪個假設能讓學生可以測試糖溶解在水中的時間？

A. 糖的量越大，溶解它所需的水越多。
B. 水越冷，溶解糖需要的攪拌速度就越高。
C. 水越暖，溶解的糖就越多。
D. 水越暖，糖溶解的時間就越長。

28. 一群消費者用不同尺寸的發動機（公升）測量汽車行駛的距離(每升公里數)。結果如下：



以下哪個描述了變項之間的關係？

A. 發動機越大，汽車每升公里數就越高。
B. 汽車每升公里數越少，發動機越小。
C. 發動機越小，汽車每升公里數就越高。
D. 汽車每升公里數越高，發動機越大。

Direction: Questions 29 to 32 refer to the scenario below.

A study was done to see if leaves added to soil has an effect on tomato production. Tomato plants were grown in four large containers. Each container had the same kind and amount of soil. One container had 15 kg of rotted leaves mixed in the soil and a second had 10 kg. A third container had 5 kg and the fourth had no leaves added. Each container was kept in sun and watered the same amount. The number of kilograms of tomatoes produced in each container was recorded.

29. What is the hypothesis being tested?

A. The greater the amount of sunshine, the greater the amount of tomatoes produced.
B. The larger the container, the greater the amount of leaves added.
C. The greater the amount of water added, the faster the leaves rotted in the container.
D. The greater the amount of leaves added, the greater the amount of tomatoes produced.

30. What is a controlled variable in this study?

A. Amount of tomatoes produced in each container.
B. Amount of rotted leaves added to the containers.
C. Amount of soil in each container.
D. Number of containers receiving rotted leaves.

31. What is the dependent variable?

A. Amount of tomatoes produced in each container.
B. Amount of rotted leaves added to the containers.
C. Amount of soil in each container.
D. Number of containers receiving rotted leaves.

32. What is the independent variable?

A. Amount of tomatoes produced in each container.
B. Amount of rotted leaves added to the container.
C. Amount of soil in each container.
D. Number of containers receiving rotted leaves.

方向：問題 29 至 32 參考下面的情景。

一項研究在確定添加到土壤中的葉子是會對番茄的生產有所影響。番茄植物將放在四個大容器中生長。每個容器都有相同種類和份量的土壤。一個容器在土壤中混合 15 千克腐爛的葉子，第二個容器具有 10 千克。第三個容器有 5 千克，第四個沒有添加腐爛的葉子。每個容器將保持充足的陽光並澆相同份量的水。每個容器中生產的番茄(千克數)將作記錄。

29. 這項研究測試的假設是什麼？

A. 光的照量越大，生產的番茄越多。
B. 容器越大，添加的葉子量越大。
C. 加入的水量越多，葉子在容器中腐爛的越快。
D. 加入的葉子越多，生產的番茄量就越大。

30. 這項研究的控制變項是什麼？

A. 每個容器中生產的番茄數量。
B. 添加到容器中的腐爛葉子數量。
C. 每個容器中的土壤份量。
D. 接收腐爛葉子的容器數量。

31. 這項研究的應變項是什麼？

A. 每個容器中生產的番茄數量。
B. 添加到容器中的腐爛葉子數量。
C. 每個容器中的土壤份量。
D. 接收腐爛葉子的容器數量。

32. 這項研究的獨立變項是什麼？

A. 每個容器中生產的番茄數量。
B. 添加到容器中的腐爛葉子數量。
C. 每個容器中的土壤份量。
D. 接收腐爛葉子的容器數量。

33. A student is investigating the lifting ability of magnets. He has several magnets of different sizes and shapes. For each magnet, the student weighs the amount of iron filings it picks up. How is the lifting ability of magnet defined in the experiment?

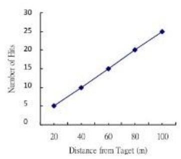
A. The size of the magnet in use.
B. The weight of the magnet picking up things.
C. The shape of the magnet in use.
D. The weight of the iron filings picked up.

34. Twenty-five shots are fired at a target from several distances. The table below shows the number of hits in 25 shots at each distance.

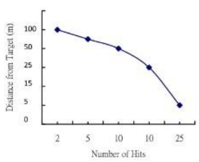
Distance from Target (m)	Number of Hits
5	25
15	10
25	10
50	5
100	2

Which graph represents the data?

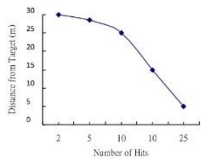
A.



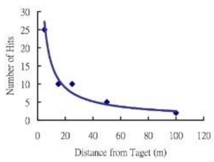
B.



C.



D.



33. 一名學生正在研究磁鐵提升物件的能力。他有幾個不同大小和形狀的磁鐵，對於每個磁鐵，學生測量它拾取的鐵屑重量。如何在實驗中定義磁鐵提升物件的能力？

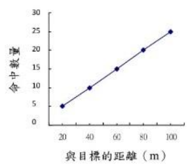
A. 使用中的磁鐵尺寸。
B. 使用中的磁鐵重量。
C. 使用中磁鐵的形狀。
D. 被拾取的鐵屑重量。

34. 李老師從幾個距離向目標發射了二十五發子彈。 下表顯示了在每個距離命中目標的數量。

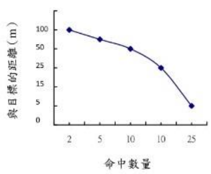
與目標的距離（m）	命中數量
5	25
15	10
25	10
50	5
100	2

以下哪個圖表能表達圖表中的數據？

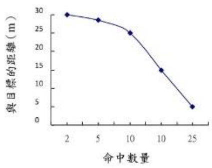
A.



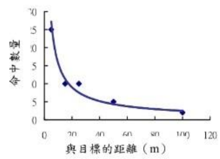
B.



C.



D.



35. Anna has an aquarium in which she keeps goldfish. She notices that the fish are very active sometimes but not at others. She wonders what affects the activity of the fish. What is a hypothesis she could test about factors that affect the activity of the fish?

A. The more you feed fish, the larger the fish become.
B. The more active the fish, the more food they need.
C. The more oxygen in the water, the larger the fish become.
D. The more light on the aquarium, the more active the fish.

36. Mr. Lee has an electric house and is concerned about his electric bill. He decides to study factors that affect how much electrical energy he uses. Which variable might influence the amount of electrical energy used?

A. The amount of television the family watches.
B. The location of the electric meter.
C. The number of baths taken by family members.
D. A and C.

End

35. 安娜有一個養著金魚的養魚缸。她注意到魚有時非常活躍而有時不是，她想知道影響魚類活動的因素。以下哪個假設可以測試影響魚類活動的因素？

A. 餵魚越多，魚變得越大。
B. 魚越活躍，他們需要的食物就越多。
C. 水中的氧氣越多，魚就越大。
D. 養魚缸的光越多，魚的活動越多。

36. 李先生有一個用電能的房子，所以他擔心電費。他決定研究影響他使用電量的因素。以下哪個變項可能影響使用的電量？

A. 家人看電視的數量。
B. 電錶的位置。
C. 家庭成員洗澡的次數。
D. A和C 。

全卷完

Appendix 6. Learning achievement Test (LAT)

2018-2019/LAT/S2/Science/ P.1/18

KAU YAN COLLEGE

2018 – 2019 Learning Achievement Test

S.2 Science

Date: 9-2018 Name:______________

Time Allowed: 75 minutes Class:S2____________

Max. Mark: 100 Class no.:___________

INSTRUCTIONS

1. There are **Five Sections** in this exam paper. Attempt **ALL** questions.

2. Answers to all Sections should be written in the spaces provided in the Answer Sheet.

3. The diagrams in this paper are not necessarily drawn to scale.

4. In Section E, questions marked with asterisk (*) **MUST** be answered in complete sentences wherever appropriate; *otherwise a mark penalty will be imposed*.

5. Use a pencil to draw diagrams.

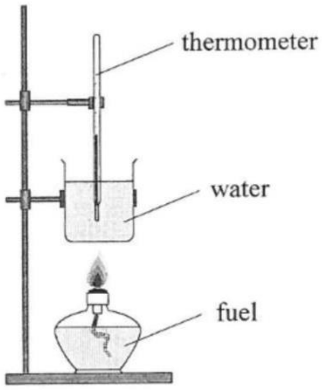
6. Use a blue or black ball pen to answer the questions.

Section A Multiple Choice Questions (20 marks, @1)

1. Which of the following descriptions about breathed air is correct?

   A. It relights a glowing splint.
   B. It contains many different gases.
   C. It contains no oxygen.
   D. It is white in colour.

2. In an experiment, the same mass of each of the three fuels P, Q and R is burnt completely to heat up a given mass of water placed in a beaker as shown below:



The table below lists the initial and final temperatures of the water recoded in each trial of the experiment:

	P	Q	R
Initial temperature of water (^{0}C)	25	30	20
Final temperature of water (^{0}C)	40	85	62

Which of the followings represents the three fuels arranged in an increasing order of energy content?

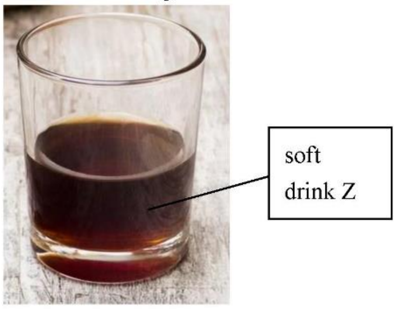
A. P < Q <R
B. P < R <Q
C. Q <P <R
D. Q <R <P

3. What substances does cigarette smoke contain?
   (1) Nicotine
   (2) Tar
   (3) Carbon monoxide

   A. (1) only
   B. (1) and (3) only
   C. (2) and (3) only
   D. All of the above

4. The photo below shows a cup of soft drink Z. It tastes sour and has a very dark colour. Mr. Lee wants to find out the pH value of this soft drink Z. Which of the following is/are suitable for the testing?
   (1) pH meter
   (2) Universal indicator
   (3) Blue litmus solution

   A. (1) only
   B. (2) only
   C. (1) and (2) only
   D. (1) and (3) only



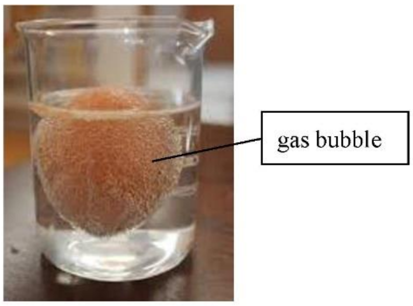
5. Which of the followings has a pH value greater than 7?

   A. Lemon juice
   B. Vinegar
   C. Soft drink
   D. Antacid

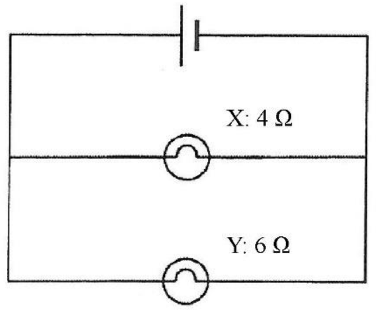
6. The diagram below shows an egg placing into a beaker of vinegar for a while. It is found that some gas bubbles appear on the surface of the egg shell

   The gas bubbles given out can

   A. relight a glowing splint.
   B. give a ‘pop’ sound when they burn in air.
   C. turn lime water milky.
   D. turn red litmus paper blue.



7. Consider the following circuit, in which two light bulbs, X and Y, are of ***different resistance***:

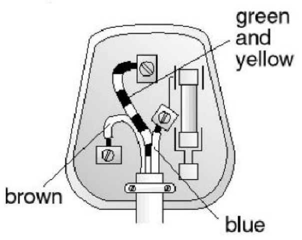


Which of the following descriptions about the circuit must be correct?

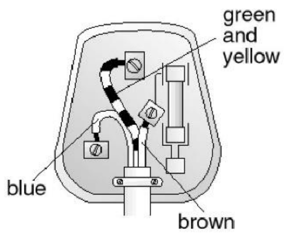
A. The current passing through X is larger than that through Y.
B. The current passing through X is smaller than that through Y..
C. Light bulb Y is brighter than light bulb X.
D. The brightness of X and that of Y are the same.

8. Which of the following plugs is wired correctly?

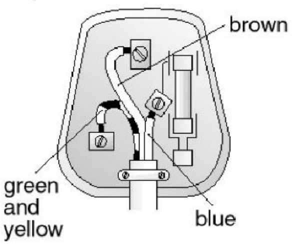
A.



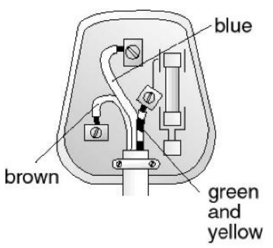
B.



C.

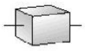


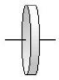
D.



9. The following objects are all made of the same material that conducts electricity. Which object has the ***smallest*** resistance?

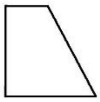
A.

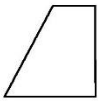
B.


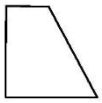
C.


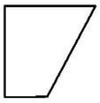
D.

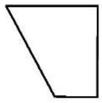
10. When we look at the following object, what is its image formed on the retina of our eyes?



A.


B.


C.


D.


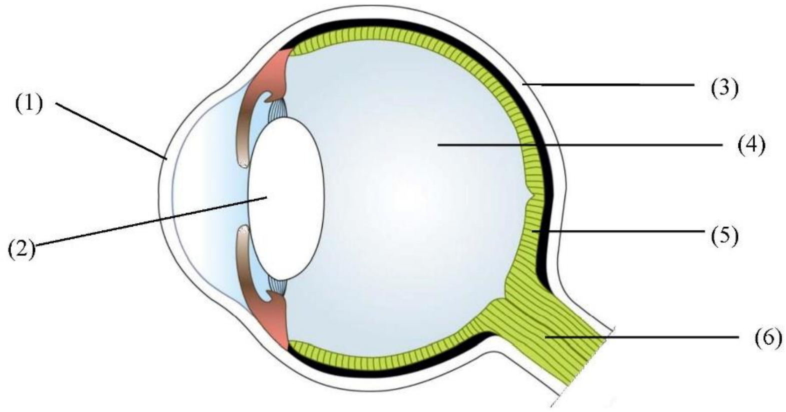
11. The diagrams below show the same eye of a person at two different times.

time P ***time Q***

What has happened between time P and time Q?

A. The person walked into a dark room.
B. The eye was shone by bright light.
C. The eye opened and then closed.
D. The eye focused on a near object.

Directions: Questions 12 to 14 refer to the diagram below which shows the structures of an human eye.



12. Which part of the eye has receptors?

A. (1)
B. (2)
C. (4)
D. (5)

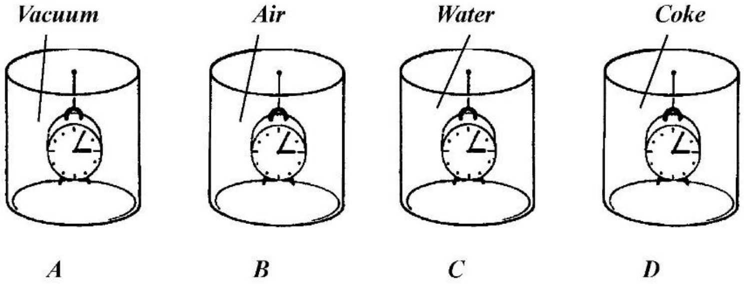
13. Which parts of the eye are responsible for focusing light?

A. (1) and (2) only
B. (1), (2) and (3)
C. (1), (2) and (4)
D. (1), (2) and (5)

14. What will happen if structure (6) of the eye is damaged?

A. The eye cannot focus light onto the retina.
B. The eye cannot send messages to the brain.
C. The eye cannot obtain nutrients.
D. The part of the brain responsible for sight cannot function properly.

15. The diagrams below show four water-proof clock***s*** inside the four boxes of different media. In which condition that the clock ticking can be heard ***the loudest***?



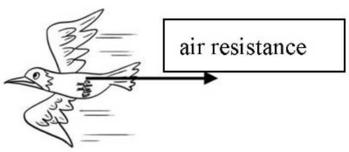
A. Vacuum
B. Air
C. Water
D. Coke

16. Which of the following stimuli can our skin detect?
(1) Touch
(2) Pain
(3) Temperature

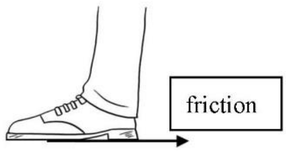
A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. All of the above

17. The diagrams below are drawn with an arrow to represent friction / air resistance. Which of the following diagrams is *incorrect*?

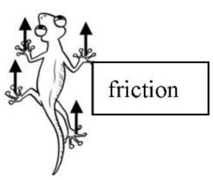
A. A bird flying forwards



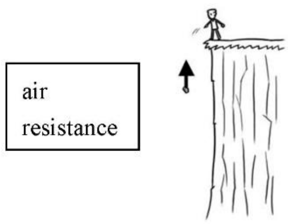
B. A man walking forwards



C. A lizard crawling upwards



D. A stone falling in air



18. Which of the following instruments can be used to measure forces?

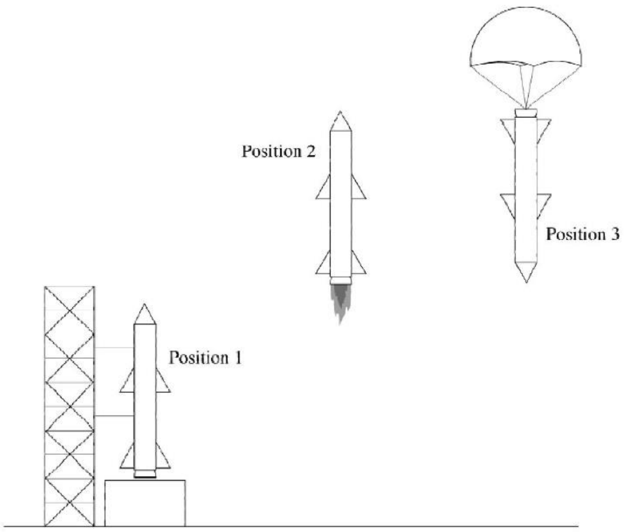
A.

B.

C.

D.

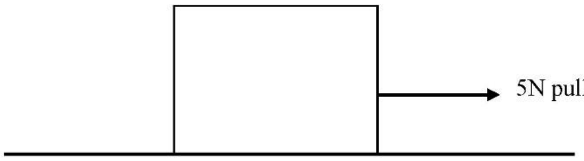
19. The drawings below show a rocket being launched from Earth and then returning.



In which of the three positions does ***gravity act on the rocket***?

A. 3 only
B. 1 and 2 only
C. 2 and 3 only
D. 1, 2 and 3

20. The diagram below shows a block that is pulled by Mr. Mak with 5 N towards the right and the block just starts to move. What is the friction between the ***block and the floor surface*** ?

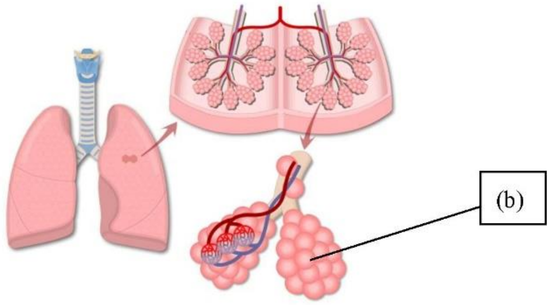


A. 0 N
B. 5 N to the left
C. 5 N to the right
D. 10 N to the left

Section B Fill in the Blanks (20 marks, @2)

1. The (a) ______________ of breathed air is higher than that of unbreathed air.

2. Gaseous exchange is carried out in the (b) ______________ in our lungs.



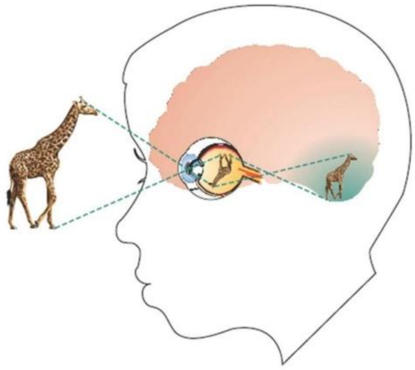
3. Mixing sodium hydroxide solution and hydrochloric acid is a common example of (c)______________ in laboratory. They react with each other to form salt and (d)______________.

4. A (e)______________ is a resistor with an adjustable resistance. It can be used to adjust the size of the current in a circuit.

5. If the current passing through the fuse exceeds its fuse rating, the fuse will blow. It prevents the circuit from (f)______________.

6. The messages from the retina of the eyes are sent to the brain along the (g)________________.

7. The image on the retina is inverted while that interpreted in the brain is (h) ___________.



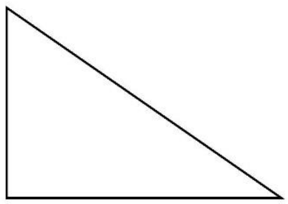
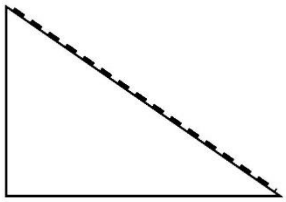
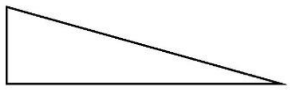
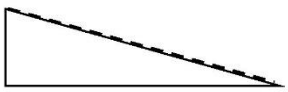
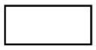
8. Ancient people made fire by drilling a wooden stick into a log.

This makes use of the (i)______________ effect of friction.

9. Engine oil and grease can help reduce friction. They are called (j)______________.

Section C Matching (10 marks)

1. Miss Wong asks you to design a fair test to investigate ***the factor of friction*** that affects ***the time of an object to slide down a wedge***. You are provided with the following apparatus.

1. Large wedge with smooth plane 	X 2	2. Large wedge with rough plane 	X 2
3. Small wedge with smooth plane 	X 2	4. Small wedge with rough plane 	X 2
5. Small blocks 	X 2	6. Large blocks 	X 2
7. Stopwatch	X 1	8. Metre rule	X 1

To carry out the investigation, Miss Wong has to consider the following items.

(i) independent variable	(ii) dependent variable	(iii) controlled variables
		A (given)

Identify the variables of the investigation by writing the ***letters into the boxes provided.***

A. The mass of the block

B. The size of the block

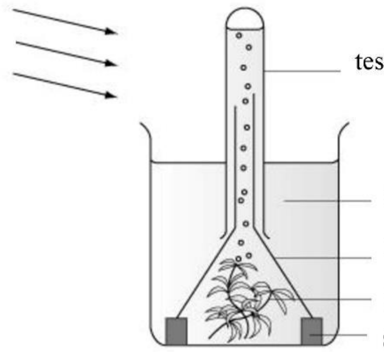
C. The sliding distance of the box on the contact surface of the wedge

D. The size of the wedge

E. The kind of contact surface

F. The time for the box to slide down the wedge

2. Mr. Lee wants to design a fair test to investigate the factor of ***concentration of carbon dioxide*** that affects ***the rate of photosynthesis*** of plants. The diagrams below show his experimental set-up of the investigation. (Remark: sodium hydrogencarbonate solution provides carbon dioxide for the plant)



To carry out the investigation, Mr. Lee has to consider the following items.

(i) independent variable	(ii) dependent variable	(iii) controlled variables
		D (given)

Identify the variables of the investigation by writing the ***letters into the boxes provided***.

A. The concentration of the sodium hydrogencarbonate solution

B. The intensity of light

C. The number of gas bubbles released from the plant in a fixed period

D. The temperature of the sodium hydrogencarbonate solution.

E. The kind of green aquatic plant.

F. The amount of green aquatic plant.

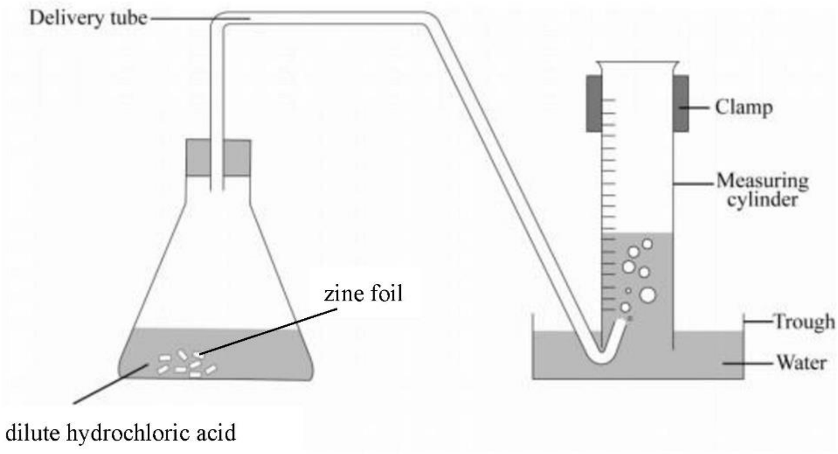
Section D Short Questions (25 marks)

1. Write ***a word equation*** of respiration in a plant cell. (2 marks)

2. Three identical candles are placed in the three jars shown below and lit at the same time. Jars Y and Z are then sealed with lids, and Jar X is left open.

Which candle flame will go out first (X, Y, or Z)? Explain your answer. (3 marks)

3. The diagram below shows a study of the reaction between dilute hydrochloric acid and zinc foils.



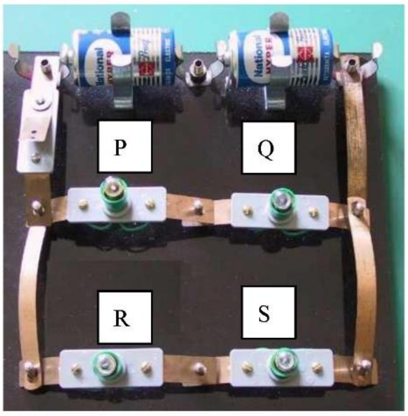
When the zinc foils are put into the acid, gas bubbles are given out from the zinc foils.

(a) What is the gas given out from the zinc foils? (1 mark)

(b) Suggest a test for the gas obtained in (a)? (2 marks)

(c) What happens to the zinc foils during the experiment? (1 mark)

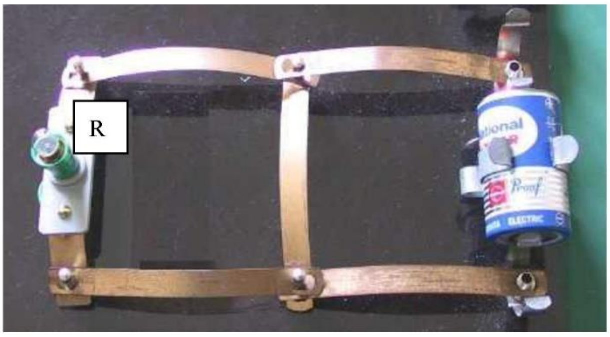
4. The diagram below shows a circuit with four identical light bulbs P, Q, R and S, two batteries and a switch.



(a) Draw a circuit diagram of the circuit in the space provided. (3 marks)

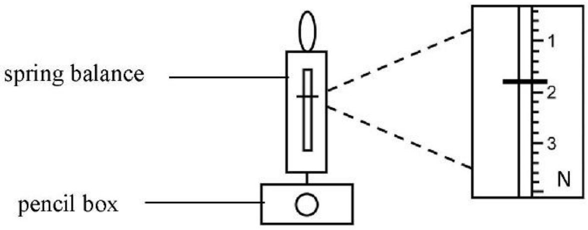
(b) What will happen to bulbs P, Q and R if bulb S is broken? (3 marks)

(c) The circuit below show how bulb R is connected with a battery.



Explain why bulb R does not light up finally. (2 marks)

5. The diagram below shows the measuring of the weight of pencil box by using a spring balance on the earth. It is assumed that 1kg is equal to 10 N on the Earth.



(a) What is the weight of the pencil box on the Earth? (1 mark)

(b) What is the mass of the pencil box on the Earth? (1 mark)

(c) What will be the mass of the pencil box if it is measured on the moon? (1 mark)

LAC Question

6. Describe and explain how the intercostal muscles and the diaphragm work together to allow us to breathe in by completing the following paragraph. (5 marks)

(Marks will be given by using appropriate signal words for sequencing and cause-and-effect)

When we breathe in, the intercostal muscles ____

____

____

____

____

____

____

Section E Long Questions (25 marks)

LAC Question

1. (a)* Describe the cause of acid rain. (4 marks)

   (Marks will be given by using appropriate signal words for cause-and-effect)

   (b) Suggest an effect of acid rain on the growth of plants. (1 mark)

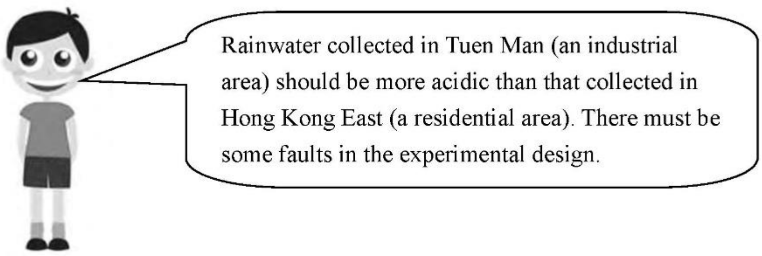
   (c) Peter and David are classmates. They respectively live in Tuen Mun and Hong Kong East. They made an attempt to study acid rain in Hong Kong. Their experimental design is shown as follows:

   Each of them
   (1) collect a rainwater sample in an open area on the roof of the building they lived,
   (2) Bring the rainwater sample back to school,
   (3) Measure the pH value of the rainwater sample using pH paper.

   The table below lists their experimental results:

District	Tuen Mun	Hong Kong East
pH value of rainwater sample	6	4

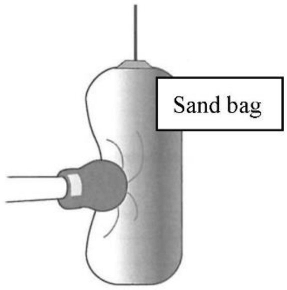
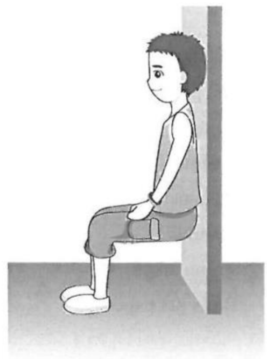
   Peter made the following comments about the experimental results:



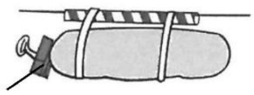
   Suggest one possible fault in the experimental design and one improvement that can be made. (2 marks)

(Total: 7 marks)

2. (a) Draw arrows (⟶) and label the name of forces (action and reaction pairs) in the figures below.

(i) A man is hitting a sandbag. (Label the horizontal forces only) (1 mark)	(ii) A man is leaning on the wall as shown. (Label two pairs of forces) (2 marks)
	

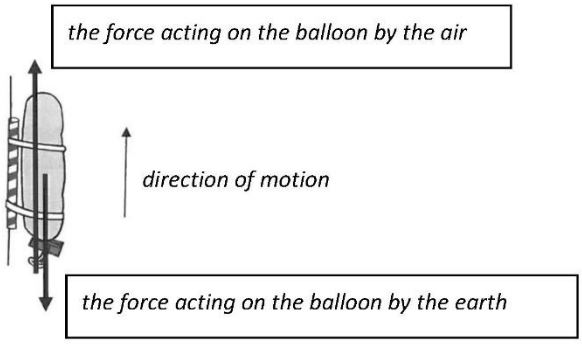
(b) The diagram below shows a balloon rocket.



(i) What will happen when the clip is removed? (1 mark)

(ii)*Explain the movement of the balloon. (2 marks)

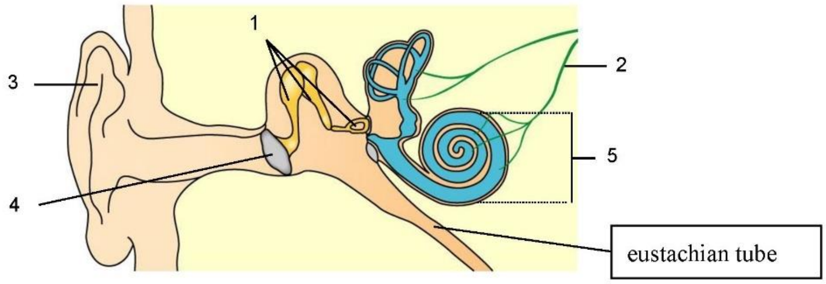
The diagram below shows the forces acting on the balloon during the ball is moving upwards.



(iii) Are the forces above belong to action and reaction pairs? Why? (2 marks)

(Total: 8 marks)

3. The diagram below shows the structure of a human ear.



(a) Name structure 1 and write down one of its function. (2 marks)

(b) Name structure 4 and write down one of its function. (2 marks)

(c) Which two structures (1 to 5) vibrate during hearing? (1 mark)

(d) When a man gets influenza, his eustachian tube will usually be blocked due to bacterial infection. Suggest how this will affect the man from hearing? (2 marks)

(e)* Describe how the sense of hearing can be produced when hitting a gong near the ear.

(3 marks)

(Total: 10 marks)

End of Question Paper

Appendix 7. Interview Protocol

P.1

Interview protocol

Interview Protocol: Improving Students' Self-Regulated Learning Abilities, Cognitive Performance and Science Process Skills through Flipped Classroom Approaches in a Hong Kong Secondary School

Time of interview:
Date:
Place:
Interviewer:
Interviewee:
Position of interviewee: Pedagogy: FPOE / TFC (Class ________ no.______)
Gender: __________

Questions:

About out-of-class online learning

1: How long did you spend on watching the videos (including the content and experimental videos) before the science lessons in general? Did you re-watch them? If yes, how many times on the re-watching? And why?

2: Which kind of videos, content or experimental videos, is more useful for you in learning the science topic? Explain briefly.

3: Are the quizzes after videos useful for your understanding on the science content? Explain briefly.

P.2

4: Can you list out which videos you find the most interesting / useful? how can it help you to learn the science knowledge and process skills*?

5: Can you list out which POE activity you find the most interesting / useful? how can it help you to learn the science knowledge and process skills? (for students who participated in the FPOE pedagogy)

6: Describe and explain some strategies you have been used to help you learn in the out-of-class online environment? e.g. making notes, speaking aloud, etc.

7: Did you encounter any difficulty on making preparation online in the PowerLesson2 platform? What are they? How could you overcome them?

8: How you performed in the flipped learning online in general?

9: What is your overall feeling about watching videos and finishing quizzes online / POE activities (for students who participated in the FPOE pedagogy) as the preparation tasks before the science lessons?

P.3

About in-class face-to-face learning

10: How can the videos and online quizzes / POE activities (for students who participated in the FPOE pedagogy) help you prepare and conduct the scientific inquiries (SI) in the science lessons?

(a) For formulating your own research question for inquiry

(b) For designing the investigation (e.g. identifying variables, stating hypothesis

(c) For collecting data (e.g. what variable to be measured and how it can be measured; why the data you collected is important for the inquiry)

(d) For interpreting data (e.g. making explanation and graph interpretation)

(e) For drawing conclusion (e.g. considering a variety of ways of interpreting evidence when making conclusions, connect conclusions to scientific knowledge)

11: What is your overall feeling about the in-class activities in our flipped classroom learning?

12. Other follow-up questions:

Remark: Thank the interviewee and assure him / her on the confidentiality of this interview

Appendix 8. Approval letter for ethical review given by HERC

香港教育大學
The Education University
of Hong Kong

9 October 2018

Mr LEE Lit Hong
Doctor of Education Programme
Graduate School

Dear Mr Lee,

Application for Ethical Review <Ref. no. 2018-2019-0012>

I am pleased to inform you that approval has been given by the Human Research Ethics Committee (HREC) for your research project:

Project title: Improving Students' Self-Regulated Learning Abilities, Cognitive Performance and Science Process Skills through Flipped Classroom Approaches in a Hong Kong Secondary School

Ethical approval is granted for the project period from 9 October 2018 to 28 June 2019. If a project extension is applied for lasting more than 3 months, HREC should be contacted with information regarding the nature of and the reason for the extension. If any substantial changes have been made to the project, a new HREC application will be required.

Please note that you are responsible for informing the HREC in advance of any proposed substantive changes to the research proposal or procedures which may affect the validity of this ethical approval. You will receive separate notification should a fresh approval be required.

Thank you for your kind attention and we wish you well with your research.

Yours sincerely,

[redacted]

Patsy Chung (Ms)
Secretary
Human Research Ethics Committee

c.c. Professor CHOU Kee Lee, Chairperson, Human Research Ethics Committee

香港新界大埔露屏路十號
10 Lo Ping Road, Tai Po, New Territories, Hong Kong
T (852) 2948 8888 F (852) 2948 6000 www.eduhk.hk

Appendix 9. Consent form for school

THE EDUCATION UNIVERSITY OF HONG KONG
Department of Science and Environmental Studies (SES)

CONSENT TO PARTICIPATE IN RESEARCH (FOR SCHOOL)

Improving Students' Self-Regulated Learning Abilities, Cognitive Performance and Science Process Skills through Flipped Classroom Approaches in a Hong Kong Secondary School

My school hereby consents to participate in the captioned project supervised by Prof. YEUNG Yau Yuen and conducted by Mr. LEE Lit Hong, who are staff / student of The Department of Science and Environmental Studies in The Education University of Hong Kong.

I understand that information obtained from this research may be used in future research and may be published. However, our right to privacy will be retained, i.e., the personal details of my students'/teachers' will not be revealed.

The procedure as set out in the **attached** information sheet has been fully explained. I understand the benefits and risks involved. My students'/teachers' participation in the project are voluntary.

I acknowledge that we have the right to question any part of the procedure and can withdraw at any time without negative consequences.

Signature:	
Name of Principal/~~Delegate~~*:	(~~Prof/Dr/~~Mr/~~Mrs/Ms/Miss~~*) CHOW Ka Kui
Post:	Principal
Name of School:	Kau Yan College
Date:	

(please delete as appropriate)*

INFORMATION SHEET

Improving Students' Self-Regulated Learning Abilities, Cognitive Performance and Science Process Skills through Flipped Classroom Approaches in a Hong Kong Secondary School

Your school is invited to participate in a project supervised by Prof. YEUNG Yau Yuen and conducted by Mr. LEE Lit Hong, who are staff / student of the Department of Science and Environmental Studies in The Education University of Hong Kong.

The introduction of the research

This research is a mixed-methods study on investigating the effect of how the two different flipped classroom (FC) pedagogical approaches: Traditional flipped classroom (TFC) and Flipped Predict-Observe-Explain (FPOE) classroom improve students' Self-regulated Learning (SRL) abilities, Cognitive Performance (CP) and Science Process Skills (SPS). S.2 students in four classes (n= 128) with different learning abilities (higher and lower achievers) will be engaging in either one of the pedagogical approaches of flipped classroom (FC), in which lectures will be arranged outside the class in form of short videos (for TFC) or in form of short videos and P-O-E activities (for FPOE) while extra lesson time gained in the classroom will be used for scientific inquiry that is student-centered. A school-based online platform will be used for affording the pre-lessons videos with follow-up quizzes (for both of the TFC and FPOE) and POE activities (for FPOE).

The methodology of the research

This research is a mixed-methods embedded design which includes quantitative data collections from pre- and post- surveys and tests, and supplementary qualitative data collection from lesson observations and focus-group interviews of students. 128 students from the four Secondary 2 (Grade-8) classes with will participate in this research. 64 of them from 2A (higher achieving class) and 2C (lower achieving class) will be engaged in the Traditional Flipped Classroom (TFC) as a control group while another 64 of them from 2B (higher achieving class) and 2D (lower achieving class) will be engaged in the Flipped Classroom with P-O-E activities (FPOE) as an experimental group that last for 7 months from September, 2018 to March, 2019. Students in these two groups are required to participate in a questionnaire survey about Self-regulated Learning (SRL) abilities (20 minutes), and Cognitive Performance tests (CPT) (75 minutes) and Science Process skills tests (SPST) (60 minutes) during the science lessons in September 2018 and March 2019 respectively. Lesson observations about the scientific inquiry of different topics will be conducted among different classes. After the Flipped Classroom (FC) interventions, focus group interviews of students (45 minutes) will be carried out and audio-taped after school in the science laboratory in March, 2019. For the interviews, students will be selected by mean of purposeful selection for detailed exploration and better understanding of the typicality and extreme cases. At last, quantitative data including students' SRL abilities, CP and SPS in the last academic year

(2017-2018) will also be obtained through the school database, survey and test from the S.3 students (n=64) in September 2018, as the additional control group data for further comparison and analysis.

The learning experiences students gained from the interventions of different flipped pedagogical approaches will hopefully improve their self-regulated learning abilities, the cognitive understanding of science knowledge and science process skills. There are also no potential risks for the students who participate in this research.

Please understand that your students'/teachers' participation are voluntary. They have every right to withdraw from the study at any time without negative consequences. All information related to your students'/teachers' will remain confidential, and will be identifiable by codes known only to the researcher.

The results of this research will be published in the form of thesis. A copy of the thesis will be provided for your school if needed. Oral presentation of the results will also be given to the participants. If you would like to obtain more information about this study, please contact Mr. LEE Lit Hong at telephone number [redacted] or his supervisor Prof. YEUNG Yau Yuen at telephone number [redacted].

If you have any concerns about the conduct of this research study, please do not hesitate to contact the Human Research Ethics Committee by email at hrec@eduhk.hk or by mail to Research and Development Office, The Education University of Hong Kong.

Thank you for your interest in participating in this study.

Mr. LEE Lit Hong
Principal Investigator

Appendix 10. Consent form for participants

THE EDUCATION UNIVERSITY OF HONG KONG
Department of Science and Environmental Studies (SES)

CONSENT TO PARTICIPATE IN RESEARCH

Improving Students' Self-Regulated Learning Abilities, Cognitive Performance and Science Process Skills through Flipped Classroom Approaches in a Hong Kong Secondary School

I ___________________ hereby consent to participate in the captioned research supervised by Prof. YEUNG Yau Yuen and conducted by Mr. LEE Lit Hong, who are staff / student of the Department of Science and Environmental Studies in The Education University of Hong Kong.

I understand that information obtained from this research may be used in future research and may be published. However, my right to privacy will be retained, i.e., my personal details will not be revealed.

The procedure as set out in the **attached** information sheet has been fully explained. I understand the benefits and risks involved. My participation in the project is voluntary.

I acknowledge that I have the right to question any part of the procedure and can withdraw at any time without negative consequences.

Name of participant ____

Signature of participant ____

Date ____

INFORMATION SHEET

Improving Students' Self-Regulated Learning Abilities, Cognitive Performance and Science Process Skills through Flipped Classroom Approaches in a Hong Kong Secondary School

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students (n=64) in September 2018, as the additional control group data for further comparison and analysis.

The learning experiences students gained from the interventions of different flipped pedagogical approaches will hopefully improve their self-regulated learning abilities, the cognitive understanding of science knowledge and science process skills. There are also no potential risks for the students who participate in this research.

Your participation in the project is voluntary. You have every right to withdraw from the study at any time without negative consequences. All information related to you will remain confidential, and will be identifiable by codes known only to the researcher. Oral presentation of the results will also be given.

If you would like to obtain more information about this study, please contact Mr. LEE Lit Hong at telephone number [redacted] or his supervisor Prof. YEUNG Yau Yuen at telephone number [redacted]

If you have any concerns about the conduct of this research study, please do not hesitate to contact the Human Research Ethics Committee by email at hrec@eduhk.hk or by mail to Research and Development Office, The Education University of Hong Kong.

Thank you for your interest in participating in this study.

Mr. LEE Lit Hong
Principal Investigator

Appendix 11. Consent form for parents of participants

THE EDUCATION UNIVERSITY OF HONG KONG
Department of Science and Environmental Studies (SES)

CONSENT TO PARTICIPATE IN RESEARCH

Improving Students' Self-Regulated Learning Abilities, Cognitive Performance and Science Process Skills through Flipped Classroom Approaches in a Hong Kong Secondary School

I ___________________ hereby consent to my child participating in the captioned research supervised by Prof. YEUNG Yau Yuen and conducted by Mr. LEE Lit Hong, who are staff / student of the Department of Science and Environmental Studies in The Education University of Hong Kong.

I understand that information obtained from this research may be used in future research and may be published. However, our right to privacy will be retained, i.e., the personal details of my child will not be revealed.

The procedure as set out in the **attached** information sheet has been fully explained. I understand the benefits and risks involved. My child's participation in the project is voluntary.

I acknowledge that we have the right to question any part of the procedure and can withdraw at any time without negative consequences.

Name of participant ________________________________

Signature of participant ________________________________

Name of Parent or Guardian ________________________________

Signature of Parent or Guardian ________________________________

Date ________________________________

INFORMATION SHEET

Improving Students' Self-Regulated Learning Abilities, Cognitive Performance and Science Process Skills through Flipped Classroom Approaches in a Hong Kong Secondary School

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students (n=64) in September 2018, as the additional control group data for further comparison and analysis.

The learning experiences students gained from the interventions of different flipped pedagogical approaches will hopefully improve their self-regulated learning abilities, the cognitive understanding of science knowledge and science process skills. There are also no potential risks for the students who participate in this research.

Your child's participation in the project is voluntary. You and your child have every right to withdraw from the study at any time without negative consequences. All information related to your child will remain confidential, and will be identifiable by codes known only to the researcher. Oral presentation of the results will also be given.

If you would like to obtain more information about this study, please contact Mr. LEE Lit Hong at telephone number [redacted] or his supervisor Prof. YEUNG Yau Yuen at telephone number [redacted].

If you or your child have/ has any concerns about the conduct of this research study, please do not hesitate to contact the Human Research Ethics Committee by email at hrec@eduhk.hk or by mail to Research and Development Office, The Education University of Hong Kong.

Thank you for your interest in participating in this study.

Mr. LEE Lit Hong
Principal Investigator