Using Socio-scientific Issues to Promote Students' Metacognitive Regulation, Self-efficacy and Conceptual Understanding in an Ecology Classroom

by

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Statement of Originality

I, LAU, Chun Hung Barry, 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.

Abstract

The purpose of this study is to investigate into the possibility of utilizing socio-scientific issues as a vehicle to promote students' metacognitive regulation, self-efficacy and conceptual understanding in an ecology classroom in Hong Kong. There has been little research to assess how these constructs are influenced by an issue-based inquiry classroom environment set in ecological context, and how these constructs interact with each other. The researcher has designed a metacognitive-rich environment for learning through a socio-scientific issue in a high school ecology classroom. Students' perceptions about the metacognitive orientation of the classroom environment were assessed by the Metacognitive Orientation Learning Environment Scale (Science) to provide evidence for the validity of the lesson design in creating a metacognitive-rich environment. The effect of embedding explicit metacognitive tasks into a socio-scientific issue on students' self-efficacy and metacognition were assessed through a quasi-experimental study using the Motivation Strategy for Learning Questionnaire and post-lesson individual interviews. 54 students from a Hong Kong long-established boy school participated in this study. The changes of the dependent variables under study were analyzed using an independent samples *t*-test and a 2x2 mixed-design analysis of variance to indicate the effect of this specially designed intervention in the biology classroom. The quantitative results suggested the intervention has created significant positive effects on students' metacognitive regulation and self-efficacy but not conceptual understanding. Results from the multivariate analysis of variance and Pearson correlations suggest that the three dependent variables under study are correlated. To assist in the interpretation of the quantitative findings, individual interviews with students in the intervention group were analyzed thoroughly based on the concurrent triangulation approach. The interview results showed that students had attained a higher metacognitive regulation and self-efficacy through self-regulated learning made possible by the use of metacognitive-rich socio-scientific issues. This study indicated possible relationships between the development of metacognitive regulation and self-efficacy and in secondary students.

Keywords: socio-scientific issues, metacognitive regulation, self-efficacy, self-regulated learning, science education

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To all of you, 'I love you and thank you very much!'

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List of Abbreviations

ANOVA	Analysis of variance
HKDSE	Hong Kong Diploma of Secondary Education Examination
HKSAR	Hong Kong Special Administrative Region
LASSI	Learning and Study Strategies Inventory
LEFT	Local ecological foot-printing tool
MANOVA	Multivariate analysis of variance
ME-rich SSI	Metacognitive-rich Socio-scientific Issues
MOLE-S	Metacognitive Orientation Learning Environment Scale
MSLQ	Motivational Strategies for Learning Questionnaire
MSLQ-CV	Motivational Strategies for Learning Questionnaire (Chinese Version)
NOS	Nature of Science
NSS	New Senior Secondary
PISA	Programme for International Student Assessment
ROSE	Relevance of Science Education
SEMLI-S	Self-efficacy and Metacognition Learning Inventory
SPSS	Statistical Package for the Social Science
SRL	Self-regulated learning
SSI	Socio-scientific issue
STSE	Science, technology, society and environment
TSI	Teaching science as inquiry

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Chapter 1: Introduction

1.1 Background and rationale of the study

According to the findings of the Programme for International Student Assessment (PISA) in 2015 reported by Lau and Lam (2017), Hong Kong students have good science performance and science literacy when compared to students in other regions and continue to rank as one of the top 10 in the 2015 PISA study. According to OECD (2017, p.20), science literacy is defined as ‘the ability to engage with science-related issues with scientific ideas as a reflective citizen’. Equipped with science literacy, a person could make scientific discourses based on evidences. The scientifically literate could explain, evaluate and design scientific enquiry. However, learning in Hong Kong was reported as teacher-centered, preferring recitation of scientific knowledge to learning about the nature of science and scientific inquiry. Hong Kong science classroom have been commented as teacher-centered and dominated by didactic instruction. The development of scientific inquiry skills is often put aside to emphasize the delivery of content knowledge. The official science curriculum document published by the Hong Kong Curriculum Development Council (2017) revealed a new emphasis for addressing the persistent problems in science education. It states that students should demonstrate self-directed and self-regulated learning because a self-regulated learner is capable of self-reflection to improve their own learning outcomes, which could benefit science learning.

1.2 Context of the study

Being a secondary school teacher for more than 10 years, the researcher has found that students, especially boys, tend to regard biology as a difficult topic in high school. Different factors such as the nature and content of the subject, teaching and learning styles, interests and motivation, and gender difference have potential influences on biology learning, which need to be addressed by biology educators in order to improve biology education.

1.2.1 Attributes affecting biology learning

Biology is a difficult topic to learn and to teach (Uitto et al., 2006). Before investigating into how a teacher could do to enhance learning and teaching, it is instrumental to identify the reasons why biology is regarded as a difficult subject, particularly in the Hong Kong context. In local secondary schools, both teachers and students are striving hard to overcome these teaching and learning difficulties. These difficulties, which tend to vary according to students' background including gender, nature of subject and teachers' style in delivering biology context, are discussed in the following sub-sections.

1.2.2 Gender difference in studying biology

According to the study by Uitto and colleagues (2006), there was a significant gender difference among boys and girls in their interests towards different science topics. The report showed that girls generally show a more favorable attitude towards biological topics including health and human body, while boys flavor topics related to technology, astronomy and military ones. In fact, in many schools, boys tend to experience more difficulties in learning biology than girls (Bahar, Johnstone & Sutcliffe, 1999; Prokop, Prokop & Tunnicliffe, 2007; Cimer, 2012). Zeyer (2018) reported declining popularity of science in schools, arguing for the necessity to enhance students' motivation especially in biology in different countries. Other authors concluded that males have higher systemizing ability when compared to females (Baron-Cohen, Knickmeyer & Belmonte, 2005; Zeyer et al., 2013). Literature also shows that younger boys favor science and younger girls favor languages and humanities (Alexander, Johnson & Kelley, 2012; Osborne, Erduran & Simon, 2003). However, this trend was not sustained at older ages in the study of Glynn and colleagues (2007). Based on my own recollections of students' utterances about the three science subjects, they opined that the contents of Physics and Chemistry are more systematic and based on principles that are more logical and comprehensible, whereas biology is regarded as more complex. Zeyer (2018) concluded that boys of high systemizing ability have higher motivation in learning chemistry and physics than girls. Systemizing abilities refer to how a person could perceive and understand a physical object in a system. This can be due to the nature that Physics and Chemistry are mostly ordered but biology is regarded as complex. In his study, such higher systemizing cognition could only motivate students to learn physics and chemistry, but not biology. The above studies showed that boys, different from girls, need more attention in biology education.

1.2.3 Nature of biology content knowledge

Cimer (2012) studied how students perceive different topics in biology and teachers' teaching style. Among the problems, students think that biology curriculum is overloaded with content knowledge. Moreover, the abstract and multi-disciplinary nature of biology knowledge also deters students from biology. The nature of biology with its heavily loaded contents may force students to learn the subject through rote learning. Moreover, Hong Kong, like other Asian cities, has an examination-oriented study culture. Combining with the textbook design of biology education, which tends to deliver knowledge in a linear way, the above factors could encourage memorization by students (Zeidler et al., 2002). In Hong Kong, biology has become one of the elective subjects in the New Senior Secondary curriculum since the senior secondary curriculum reform in 2009 and needs not to be taken together with any of the other science subjects. The Curriculum

Development Council and Hong Kong Examinations and Assessment Authority (2015) also reckoned that the Hong Kong Biology Curriculum has long been mistaken as emphasizing memorization of facts. The guide suggests teachers adopt different learning and teaching strategies to stimulate students' interest in biology. This shows the Hong Kong curriculum planners are eager to change the mindsets of stakeholders that biology is a boring subject to teach and learn. Hong Kong is not alone in facing such problem. Scholars suggested different explanations, ranging from the difficulties arisen from the subject nature, complex levels of conceptual organization (Lazarowitz & Penso, 1992), and the heavy curriculum (Osborne & Collins, 2001). Yüzbaşılıoğlu and Atav (2004) further argued that another reason for the present situation is that the learning environment could not cater to students' learning. When a student found that the learning environment is not up to their expectation, students' interest in biology will decrease. Hence, the researcher would like to find a way to improve student learning of biology to address the above problems.

1.2.4 Roles of the teacher in biology education

In a typical biology classroom, it is common that classroom discourse is mainly initiated and dominated by the teacher in a didactic manner. For example, in Hong Kong, Chan and Watkins (1994) and Thomas (2006) demonstrated that the classroom environment was heavily dominated by the teacher. Students had little opportunity to engage in meaningful discourse (Duschl & Osborne, 2002). Teachers adopting a didactic teaching approach often dominate the lessons with direct lectures, attempting to transfer abstract knowledge from the textbook to students without linking it to authentic life examples. More worryingly, many schools nowadays require students to remember a lot of scientific knowledge without expecting them to understand them thoroughly

(Norris, Phillips, & Osborne, 2007). Obviously, a teacher-centered classroom does little help foster students' attitudes and motivation in studying biology. All these studies imply that both students and teachers lack the essential skills in learning and teaching biology effectively. There has been a lack of discussion of socio-scientific issues (SSI) in the biology classroom as this is not the focus of high-stake assessments in Hong Kong. Ironically in the official curriculum updates on science education, Hong Kong teachers are expected to connect their teaching contents to daily life examples through the use of issues to make biology learning relevant to students' own life experiences (Hong Kong Curriculum Development Council, 2017).

1.3 The potential of utilizing socio-scientific issues to improve biology education

Different scholars have been working on ways to help overcome students' difficulties in studying biology (Lee et al., 2010). Wang (2015) summarized a series of standard documents and PISA framework to focus on the goal of developing students' abilities on the interpretation and construction of evidence-based explanation and science models. Following this goal, students could evaluate their own explanation through a judging process with the use of evidence and conclusion in a scientific inquiry learning environment. Over the decades, researchers and educators around the world called for a change in the way science education could be mediated by scientific inquiry. Eggert and colleagues (2013) emphasized the aim to engage students in lifelong learning through discussion about modern science issues from multiple perspectives. This echoes the aims of science and biology education in Hong Kong that science education should encompass the use of SSI to promote the following outcomes; (1) nurturing students' interests; (2) develop students' scientific thinking; (3) strengthening students' skills; (4) fostering students' sense of scientific evidence; and (5) nurturing students to be self-directed learners of science (Curriculum

Development Council and Hong Kong Examinations and Assessment Authority, 2015). SSI are complex and contentious issues connected to science (Zeidler, 2014), and SSI-based instruction could be a powerful strategy to enhance science education by promoting learning and scientific literacy (Presley et al., 2013). Different science educators agreed that SSI could engage students in a learning experience that connects school experience with societal contexts (Sadler, Foulk & Friedrichsen, 2017; Parker & Lo, in press; Topcu & Genel, 2014; Yoon, 2011). Presley and colleagues (2013) further proposed a framework for SSI-based education after summarizing the keys to successful SSI-based learning and teaching experiences in different studies. The framework as shown in Figure 1 consists of three core elements, namely (1) design elements, (2) learner experiences, and (3) teacher attributes, situated in the classroom environment surrounded by peripheral influences.

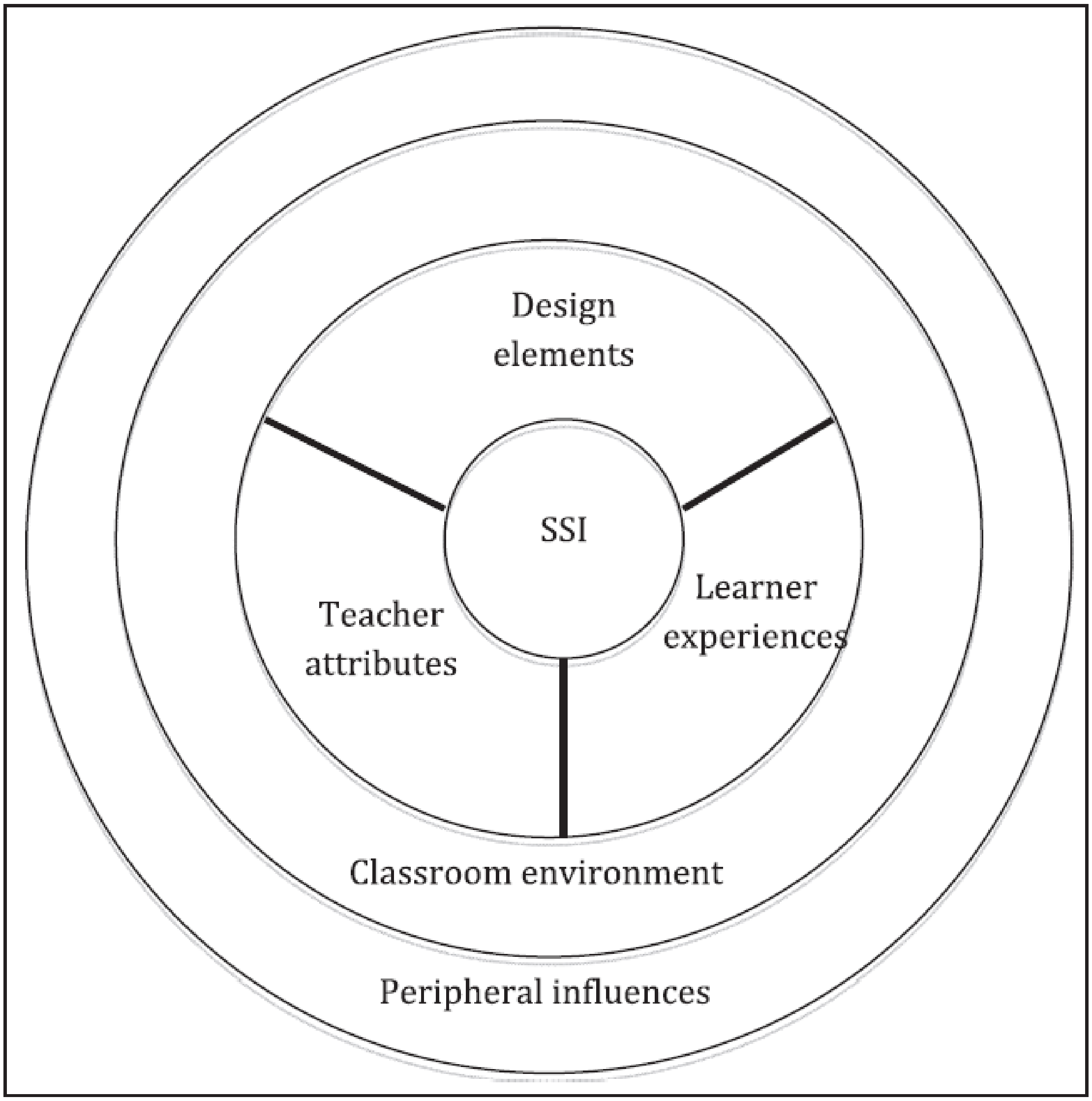

Figure 1. Graphical representation of SSI-based framework

Adapted from Presley et al. (2013)

1.4 Factors influencing SSI-based instruction

The framework of SSI-based education formulated by Presley et al. (2013) underscores the importance of the classroom environment and peripheral influences on successful SSI-based education. Peripheral influences represent a broad perspective liable to influence SSI-based education. Such influences could pose significant influences on the design of the framework. They are different concerns in the implementation of an SSI-based classroom which could affect the feasibility of such approach including the flexibility of the curriculum, accessibility to SSI-based materials, national, district and school policies, etc. Among these influences, the school posed the most significant impact on the SSI-based education (Presley et al., 2013).

The classroom environment could influence the core elements of the SSI-based science education by addressing the cognitive and affective needs of students and teachers. In a controversial SSI topic, students and teachers need to feel secured in engaging in discussion, presentation and argumentation. When it comes to the classroom environment in Hong Kong, Cheng (1994) found that classroom environment was the most powerful predictor of students' affective performance. Affective performance of students includes students' self-concept and interaction with their fellow students and the teacher. Chan and Watkins (1994) found that secondary students in Hong Kong prefer a more enjoyable and friendlier classroom environment that tended to promote students' learning outcomes. Such learning environment is important to facilitate students' self-regulated learning (SRL) (Lee, Yin & Zhang, 2009), which has the potential to enhance students' motivation that in turn creates a more effective classroom environment (Alfassi, 2004; Eshel & Kohavi, 2003; Hanrahan, 1998; Ho, 2001; Yen et al., 2005). As mentioned earlier, teacher-centeredness in Hong Kong's classroom has led to negative influence on students' motivation and learning outcomes.

Thus, the introduction of SRL could be a possible solution to alleviate the aforementioned difficulties in teaching and learning biology. In this connection, the learning approaches associated with the development of SRL, such as inquiry-based learning (Schraw, Crippen & Hartley, 2006), need to be reviewed and explored to create a learning and classroom environment conducive to SRL.

1.4.1 Zimmerman's cyclical phases model of SRL

In a review of SRL conducted by Panadero (2017), the importance of SRL in understanding the cognitive and affective aspects of learning was discussed. SRL was believed to be an important construct, having different components with potential to influence learning. Among the different models about SRL, Zimmerman's self-regulated learning model was developed based on the socio-cognitive theory of Bandura. His first model of SRL indicated the interaction among the environment, person and behavior in a triadic model (Zimmerman, 1989). From this model, he continued to develop his idea to illustrate the interaction between metacognition and motivation, culminating in a cyclical phase model (Zimmerman, 2000). This model describes SRL as a cycle of forethought, performance or volitional control and self-reflection. He further modified his cyclical phase model (Zimmerman & Moylan, 2009) (Figure 2) to show how students make use of different self-control strategies to engage themselves cognitively and be motivated to evaluate their own performance.

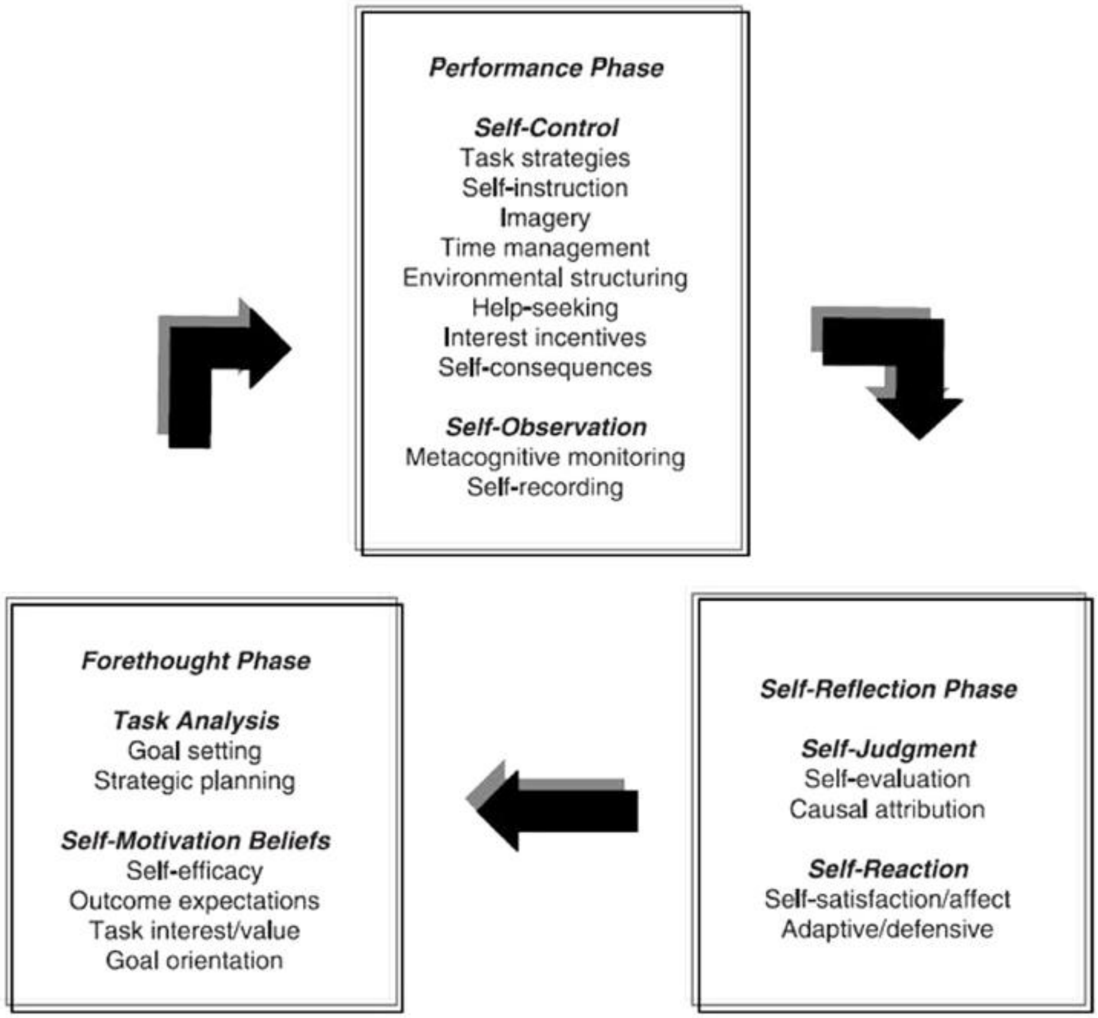

Figure 2: Current version of the cyclical phase model of SRL.

(Adapted from Zimmerman & Moylan, 2009)

1.4.2 Metacognition and self-efficacy as important components of self-regulated learning

Following Zimmerman's model, Zepeda and colleagues (2015) focused on metacognitive skills, i.e. 'planning', 'monitoring' and 'evaluation' in Zimmerman's SRL cyclical phase model. They modified the constructs in the three phases of the cyclical phase model - 'forethought', 'performance' and 'self-reflection' - to 'planning', 'monitoring' and 'evaluating' respectively. (Figure 3)

In their model, 'planning' involves several self-motivational beliefs including self-efficacy, task value, goal orientation and need for cognition. The 'monitoring' phase involves self-control, which includes effort regulation and control of learning beliefs. The 'evaluating' phase includes self-judgement with the theories of intelligence. In their intervention using this SRL model, it was found that direct instruction of metacognition could work in promoting motivational outcomes in a middle school science class, with students' self-efficacy, an essential motivational belief, having a high effect size in the planning stage.

The present thesis aims to investigate into the possibility of utilizing socio-scientific issues as a vehicle to promote students' self-efficacy and metacognitive regulation for enhancing self-regulated learning. This, hopefully, will lead to better conceptual understanding in applied ecology in a biology class in Hong Kong.

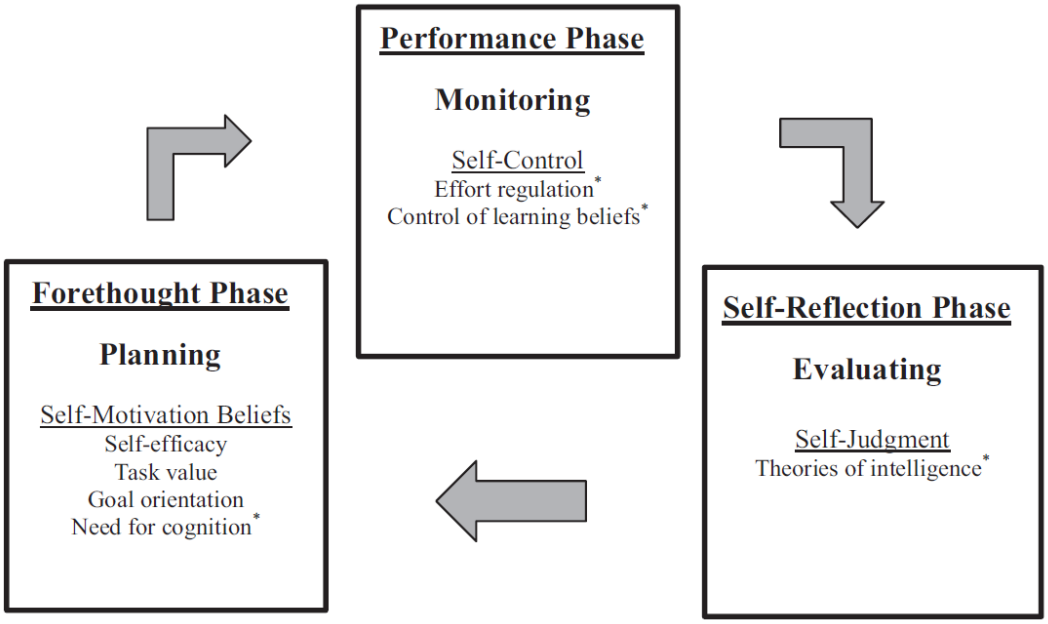

Figure 3. Phases and sub-process of self-regulated learning.

(Adapted from Zepeda et al., 2015)

1.5 Research questions

(1) What is the effect of metacognitive-rich SSI on students' metacognitive regulation?

(2) What is the effect of metacognitive-rich SSI on students' self-efficacy?

(3) What is the effect of metacognitive-rich SSI on students' conceptual understanding?

(4) How do metacognitive regulation, self-efficacy and conceptual understanding correlate with each other in metacognitive-rich SSI?

1.6 Significance of this study

Hogan (1999) reported that there have been limited studies about how epistemological and motivational factors could affect science education. Metacognitive and motivational dimensions of cognition are regarded as important factors in building students' conceptual understanding. This study aims to promote students' motivation with emphasis on metacognitive regulation and self-efficacy in the context of an SSI related to the ecology of Hong Kong. This research could provide insights for educators into the promotion of biology learning by incorporating a metacognitive-rich SSI approach to facilitate cognitive, metacognitive and affective development of students. The findings would have significant implications for pedagogical development in science education.

1.7 Organization of the thesis

This chapter first introduces the research problem and its background, followed by a brief description of the context of the study. Before elaborating on the significance of the study, the specific research questions are spelt out. Chapter 2 provides a comprehensive review of the literature relevant to the study. It details the theoretical dimensions of the present study, drawing insights from the literature, culminating in the promulgation of a conceptual framework for this study. Chapter 3 begins by detailing the research approach adopted by this study and the attendant methodological issues. The methods of data collection and analysis methods are also described. Chapter 4 discusses the major findings of this study to address the four research questions. Chapter 5 discusses the conclusion and implications of this research with due consideration to its limitations. Lastly, based on the insights gained from this research and the gaps remained to be bridged, suggestions for future studies were put forward.

Chapter 2: Literature Review

2.1 Socio-scientific issues

The relevance to daily life to science has been a concern across the world as an effort to promote science education for all. From the official curriculum document on science education in Hong Kong (Curriculum Development Council, 2017) and the curriculum and assessment guide on biology (Curriculum Development Council & Hong Kong Examinations and Assessment Authority, 2015), there have been concerns to uplift the quality and effectiveness of science education and biology education through the implementation of science, technology, society and environment (STSE) approach. Moreover, appropriate application of authentic issues in the curriculum is believed to give more life to the curriculum content, and to bridge students' learning with authentic life examples. Although the STSE approach has been introduced since 1970s to modernize the traditional way of learning science, the roles of STSE seems to be marginalized due to impeding factors like curriculum time and assessment focusing on conceptual understanding.

Presley and colleagues (2013) defined socio-scientific issues (SSI) as social problems related largely to science. These issues are open-ended, and students are challenged to respond to develop their scientific literacy. SSI have become more important as a teaching approach since the last century (Cajas, 1999; Pedretti, 1999). Such approach facilitates science learning through authentic issues that are more relevant to students' daily lives. SSI and STSE have been closely related to the 'Science for All' movement, which aims to develop scientific literacy among students (Lee, 2017). Lee and Grace (2012) argued for the importance of infusing SSI into science curriculum to uplift students' scientific literacy through the development of various skills such as critical reasoning and decision-making. Whether or not students could master such skills could affect students' conceptual understanding, interest, motivation, epistemological development and attitudes towards science (Klosterman & Sadler, 2010; Lee & Erdogan, 2007). The SSI approach emphasizes intellectual development and awareness of the interrelationship between science and society. It engages students in intellectual discussion among themselves. Due to the controversial nature of SSI, students could develop their reasoning process on which they base their decisions to resolve the issues. Sadler (2004) and Zeidler (2003) pointed out that SSI could be desirable to promote students' understanding of scientific information when students are capable of evidence-based reasoning in their learning.

The SSI approach is often compared with the STSE approach. Although they both emphasize the inter-connectedness of science, technology, society and environment, the SSI approach differs from STSE in that the former could also promote moral and emotional development of students as SSI offer opportunities for the discussion of ethical issues created by the application of science, which help promote high-order thinking and multi-perspective reasoning. Students are able to see how science-based issues could be addressed by their decisions upon reflection on moral consideration (Zeidler et al., 2005). In such setting, social interaction and discourse could play a main role in students' learning experience. SSI education is highly relevant to students' psychological development. Sadler and Zeidler (2004) proposed the application of cognitive-moral reasoning in socio-scientific issues. They postulated the understanding of the nature of science and discourse as enhancing factors for personal cognitive and moral development, which would eventually promote scientific literacy. Hence, teachers should incorporate SSI into their teaching because SSI could promote students' moral reasoning through discourse in psychological, social and emotional aspects from a cognitive-moral reasoning perspective. Such moral consideration could impact on students' decision making about SSI.

2.1.1 Utilizing SSI to promote learning outcomes

A study conducted by Zohar and Dori (2003) found that students showed significant improvements in learning when exposed to an SSI-embedded learning environment of science. The SSI approach allows students to reason and respond to an issue by applying their knowledge of the societal, cultural, environmental, political, and ethical aspects of the issue. Sadler and Dawson (2012) highlighted how SSI could promote key learning outcomes in science education. In their study, they suggested that SSI could serve as a basis for students to learn the nature of science, promote interest and motivation, and develop argumentation processes. They further defined four areas of learning outcomes that could be achieved by the SSI approach, ranging from (1) knowledge on the content, (2) nature of science, (3) interest and motivation and (4) argumentation. Sadler (2011) stated that there is no one correct way to include an SSI in science education. However, Eilks, Nielsen and Hofstein (2014) suggested that the SSI approach should carry the characteristics of being authentic, relevant and contentious, allowing open discussion in dealing with problems related to science and technology.

Researches have shown that teachers from Korea and England (Lee et al., 2006; Levinson & Turner, 2001) showed positive attitude towards teaching through SSI in biology. However, the effectiveness of utilizing SSI in these countries remained hindered because of their narrow curriculum focus, which is to a large extent fueled by their emphasis on conceptual understanding rather than on the competencies to interpret and resolve authentic science-related daily life problems. SSI education advocates argue that incorporating SSI could provide more opportunities for students to engage in discussion that does not only confined to textbook knowledge. As mentioned in the introduction chapter, the actual delivery of science in schools nowadays relies heavily on textbooks which may mislead students that scientific knowledge is linear in nature (Zeidler et al., 2002). Appropriate application of SSI in the curriculum is believed to make the curriculum contents livelier and to relate students' learning to authentic life examples. Hatano and Inagaki (1991) suggested that classroom learning could become more effective if students could contribute to discussions on SSI, for example, by asking questions, evaluating ideas and receiving feedback. Sadler and Dawson (2012) summarized the positive impact of SSI education on content knowledge retention in science education, such as reducing achievement gaps among students, larger gain in content knowledge, and better results in science achievement tests. Moreover, Tasci (2015) conducted a study to discuss the criteria for high quality biology teaching. The author argued how the incorporation of SSI in biology teaching could lead to the achievement of higher scientific accuracy and clearer concepts learnt. It is also suggested that interdisciplinary teaching has a positive influence on the learning outcome.

2.1.2 SSI, argumentation and metacognition

Driver, Newton and Osborne (2000) called for the need to reconceptualize the practices of science teaching so as to portray scientific knowledge as socially constructed. To achieve such aim, classroom discourse and argumentation are believed to play a central role in bringing changes to science education. Incorporating SSI in teaching of science and environmental education could benefit the development of students' argumentation and critical thinking skills (Lin & Mintzes, 2010; Venville & Dawson, 2010; Lee & Grace, 2012). Lee and Grace (2012) reported such skills, particular decision-making skills, could allow students to make judgment on the evidence used in their arguments. These fit with the main ideas to connect science to society and highlight the social importance of the issue (Eastwood et al., 2012).

Although argumentation is central to science and is increasingly viewed as an important instructional approach and educational goal for science education (Bell, 2004; Duschl et al., 2007; Osborne, Erduran, & Simon, 2004), it is frequently absent from typical science classrooms (Sadler, 2006). In a science classroom, however, conducting argumentation is not an easy task. Chen and She (2012) stated that many studies about argumentation showed that argumentation was conducted in the classroom for only very short periods of time. Such practice could not benefit students to improve their argumentation skills. Argumentation is a collective cognitive development process which involves complicated higher order thinking skills such as the use of evidence to support or refute a particular claim, coordinating the claims with evidence to make an argument, and forming a judgment of scientific knowledge claims, and identifying reliable and consensual scientific knowledge. The development of argumentation skills entailing high-order reasoning and application of scientific knowledge and understanding could be challenging for both teachers and students. There have been studies showing the difficulty to promote argumentation skills among students (Candan, 2006; Guven, 2002; Kivanc, 2003; Newton et al., 1999; Sandoval & Milwood, 2005). The argumentation process relies on different cognitive procedures (Pontecorvo, 1987), which require metacognition for mastery (Mason & Santi, 1994). Duschl and Osborne (2002) illustrated the articulation of students' thoughts and their argumentation with the use of metacognitive skills. Different studies showed that metacognition and argumentation are closely related (Kuhn & Udell, 2003; Kuhn et al., 2008; Mason & Santi, 1994).

2.2 Metacognition

Flavell (1979) defined metacognition as the awareness and monitoring of one's thoughts and task performance or cognition about cognition. In simple words, metacognition is referred to 'thinking about thinking'. Different researchers underscored the importance of metacognition for achieving high-quality learning (Flavell, 1979; Schraw & Moshman, 1995). Metacognition relies on the monitoring function of a person which requires the use of different strategies under different circumstances. Metacognition works as a multidimensional construct. Developmental psychologists and researchers defined metacognition in two ways. First it refers to one's knowledge concerning one's own thinking or anything about them. This could allow the learners to understand their own learning or thinking processes. Second, it refers to the analysis of one's own thinking processes (National Research Council, 2000; Perkins and Salomon, 1989). They are expanded from Flavell's original definition of metacognition which include the processes of planning, monitoring and evaluation.

There are two main components in metacognition – metacognitive knowledge and metacognitive regulation. (Brown, 1978; Jacobs & Paris, 1987). With inferior metacognition, people could not perform well. They tend to make errors and fail to recognize such errors. Moreover, they may over-estimate their own abilities (Kruger & Dunning, 1999). Metacognitive knowledge is different from cognitive knowledge in how such knowledge is used. A person requires metacognitive knowledge to strategically assess the achievement of personal goals through activities aiming to deliberate on the effectiveness of his or her cognitive skills. With such knowledge, metacognition could be an important predictor of success. Roberts (2001) concluded in his study that students with a stronger motivation could learn better and utilize metacognitive strategies in a better way. Efklides (2006,

2011) further argued that metacognitive experience has an affective component, and the interactions between metacognition and motivation are central to the concept and process of self-regulated learning. She discussed the interaction of metacognition with motivation and affect in a model of self-regulated learning at personal and task level. Avargil, Lavi and Dori (2018) discussed the importance of students' metacognition and metacognitive strategies in science education. In their study, they summarized that metacognition is important to mediate life-long learning, and engagement with metacognition is a key to deep conceptual understanding of scientific knowledge in general (Anderson & Nashon, 2007; Blank, 2000; Choi et al., 2011; Georghiades, 2004; Koch, 2001; Nielsen et al., 2009; Wang & Chen, 2014).

2.2.1 Metacognition and self-regulated learning

Metacognition and motivation are the core components of SRL (Efklides, 2006, 2011). Schunk and Zimmerman (1994, 1996, 1998) developed a conceptual framework to link different learning issues with corresponding self-regulation processes. Learning issue and key questions about 'how, when, what and with whom' to learn are related to learners' choices of self-regulation processes. The processes include strategy use, time management, self-observation, self-judgment and help seeking. These processes could be self-regulated. Researchers view the relationship between metacognition and self-regulated learning differently. Schraw & Moshman (1995) regarded self-regulated learning as a subset of metacognition. In their proposed model, metacognition comprises metacognitive knowledge and metacognitive regulation. Metacognitive knowledge refers to the knowledge of cognition including declarative, procedural and conditional knowledge. Metacognitive knowledge could build up continuously throughout the growth of a person (Brown, 1987; Garner & Alexander, 1989). For metacognitive regulation, it refers to activities that control one's thinking and learning. Metacognitive regulation is most commonly described as metacognitive planning, monitoring and evaluation (Jacobs & Paris, 1987; Schraw & Moshman, 1995).

However, some viewed self-regulation as a larger construct including metacognition as its one of its components (Schunk, 1989; Zimmerman, 1989). Self-regulated learning refers to the ability to understand and control their own learning methods and environment including goal setting, appropriate strategies and monitoring their progress. Zimmerman (2000) defined self-regulation as the way that students sustain their cognition actively and exhibited behaviors and affects which are linked to achieve the goals. This bears resemblance to metacognitive regulation. Such regulation is crucial and would affect classroom environment, hence it should be considered by teachers in tasks design. Students should be able to determine their own goals, select appropriate strategies to realize their goals, and keep monitoring their own learning progress. Moreover, Pintrich and De Groot (1990) reported that one's cognitive and self-regulatory learning strategies in learning were influenced by one's self-efficacy. High school students with higher self-efficacy ability would behave differently compared with those with lower self-efficacy. They can repeat different cognitive and self-regulatory learning strategies in learning. This finding implies that successful learners could be motivated to apply self-regulated learning strategies by raising their self-efficacy.

Thomas (2012) discussed the relationship between metacognition and self-regulated learning, and concluded they overlap with each other. He found that there is more research in science education focusing metacognition over self-regulation. Metacognition is more commonly regarded as a major component of self-regulated learning and could allow learners to have effective monitoring on their own cognitive skills. Ormrod (2010) defined self-regulation as involving self-determined goals and standards against which students judge their learning outcome. Students achieve self-monitoring through making responses, leading to self-instruction. Students will then be able to improve their own performance. Eventually, students can go through the process of evaluation on their performance quality, and make self-imposed contingencies based on their prediction of whether their goals could be achieved or not. In such sense, teachers' intervention could be a possible way to encourage and guide students' self-regulation in achieving their goals. Until then, students could attribute accurately their failure to specific factors that they could improve. From their study about increasing student engagement, self-efficacy and self-regulated learning, Perry and Steck (2015) concluded students who exhibit a high level of self-regulated learning would be more willing to apply metacognitive strategies in their learning process. In this study, metacognition is regarded as a component of the SRL model proposed by Zimmerman.

2.2.2 Metacognitive regulation (planning, monitoring and evaluation)

Brown (1994) linked the ability to assess a person's own learning repertoire to success in learning. Metacognitive planning allows students to select suitable strategies to complete a task. Planning activities included goal setting and task analysis, which facilitate the organization of given materials. With a good metacognitive planning ability, students could decide to adopt better strategy in order to solve the problem successfully in the planning stage. Students with low metacognitive planning ability would apply ineffective strategies in their learning. Throughout the learning process, students demonstrate metacognitive monitoring skills by being aware of their own learning and performance, for instance, identifying if a certain concept or objective has been mastered or not. Monitoring activities include tracking students' own attention during reading or self-questioning. After that, students shall be able to integrate their learning with prior knowledge.

The evaluation part of metacognitive regulation is called metacognitive evaluation. This could allow one's appraisal of the learning outcomes. Students demonstrating evaluation skills could review the effectiveness of the skills they applied to the task. Yuruk and colleagues (2011) summarized how students could learn better by evaluation. Through evaluation, a learner could know what should be learnt, reflect on his or her own approach and finally make adjustment if necessary. Such control of one's own cognitive process requires knowledge of learning strategies and awareness of when to apply such knowledge. Stanton and colleagues (2015) associated metacognition with students' performance. They suggested that strong metacognitive skills are associated with learning outcomes and students' performance as students could be more aware of their thinking and how to control their thinking to facilitate learning.

2.2.3 Metacognition and science education

Avargil, Lavi and Dori (2018) discussed the importance of students' metacognition and metacognitive strategies in science education. They argued that science literacy development is largely dependent on metacognitive abilities in information processing. Metacognition is important to mediate life-long learning, and engagement with metacognition is a key to deep conceptual understanding of scientific knowledge in general (Anderson & Nashon, 2007; Blank, 2000; Choi et al., 2011; Georghiades, 2004; Koch, 2001; Nielsen et al., 2009; Wang & Chen, 2014). Other researchers argued that metacognition might be able to promote different learning outcomes in science education, including improvements in understanding of scientific concepts, comprehension of scientific reading and monitoring the process of reading different scientific publications (Georghiades, 2004; Michalsky, 2013; Norris & Phillips, 2012; Wang & Chen, 2014; Wang et al., 2014). Students could benefit from metacognition in developing better conceptual understanding through understanding the construction of knowledge and being more motivated in learning science (Anderson & Nashon, 2007; Nielsen et al., 2009). In biology education, there have been research studies, ranging from genetics to ecosystem, emphasizing on the importance of metacognitive regulation to conceptual understanding (Eilam & Reiter, 2014; Martin et al., 2000; Zion, Michalsky & Mevaerch, 2005). Introducing metacognitive regulations could facilitate students to reflect on their learning processes to avoid a repeated use of ineffective learning methods like rote memorization. This could promote better and more accurate understanding of biology concepts. Echoing NRC's (2007) suggestion in the document of '*Taking science to school*', science education has to move away from the acquisition of only hard facts, but to engage students in authentic discussion through an inquiry-based pedagogy in order to enhance the quality of science learning. Newmann and colleagues (1996) claimed that one of the criteria of 'authentic intellectual work' was disciplined inquiry. Such work could enable students to engage in higher-order thinking and real-world problem-solving situation.

Moreover, a study by Brandon et al. (2009) showed that a structured inquiry-based learning program could help bridge the gap between 'real' science and school science and further promote students to think like scientists. Such discourse could provide students with an authentic learning environment and could be another benefit of the inquiry-based approach. They could be incentives for teachers to increase their willingness to design and implement inquiry-based activity, which could also provide a basis for formative assessment.

To increase the effectiveness of inquiry-based science education, Seraphin and colleagues (2012) proposed the development of metacognition. They discussed the close ties between self-regulation, motivation and metacognition. In order to foster SRL, students must understand and be responsible for their learning processes. They proposed the approach of teaching science as inquiry (TSI) (Pottenger, 2007) could relate metacognition and inquiry. In a TSI classroom, students will play the role of scientists through participating in scientific practices. Through various tasks such as question setting, data manipulation and expressing their stances and arguments, students could perform like real scientists. This provides support to revolutionalize the current curriculum by setting intellectual challenging tasks for students, thus allowing the teacher's role to shift from a knowledge deliverer to a leader and a research director. In such an inquiry approach, metacognition is likely to play a central role, as there will be greater chances to provoke teacher-to-student, student-to-teacher and student-to-student communication and discourses. The teacher could make use of these discourses to provide thoughtful feedback to students to inspire them to reflect on their learning and thinking strategies. Teachers' feedback on students' strengths and weaknesses in different aspects of their learning could also raise students' awareness to improve and regulate their studies. Their findings showed that metacognition plays a key role in the above TSI classroom. In a TSI classroom environment filled with rich contextual contents and different learning experiences, the ability of metacognition and SRL are important determinants of students' learning outcomes. This is because students in the TSI classroom need to deal with different information and at the same time to improve their motivation and strategies with considerable effort and regulation (Ormrod, 2010).

In order to become a self-regulated learner, a student should be able to regulate metacognitively in a complicated classroom setting, monitoring and evaluating their learning strategies and outcomes in an iterative manner. Trumper (2006) showed that many students ended up becoming less interested in biology mainly because of their dissatisfaction with their high school science experience, which often included memorizing and lacking intellectual challenges (Osborne & Collins, 2000). Thomas (2003) went further to argue that a setting of lesson that lacks psychosocial attributes in developing students' metacognition and over-emphasizing rote memorization in classroom will lead to unsatisfactory learning outcomes. Echoing the findings of different researchers (Baird, 1986; Tasker, 1981; White & Mitchell, 1994) that existing science classroom practices are not oriented to stimulate students to develop metacognition. Thomas suggested metacognition as one of the keys to improve students' learning outcomes and one of the requirements of a high-quality science classroom. The metacognitive activities that students go through in their journey of learning is important in determining their learning effectiveness. This is because metacognitively active students are crucial to a constructivist classroom. Thomas (1999, 2002) pointed out that the development of students' metacognition is socially mediated, which is dependent on the classroom learning environment. He emphasized the importance of identifying how students and teachers interact in a metacognitive-oriented classroom (Thomas, 2003).

In conclusion, teachers and researchers should make corresponding pedagogical changes to provide a more metacognitive-oriented learning environment to students.

2.3 Self-efficacy

According to Bandura (1986, p.391), self-efficacy was defined as 'People's judgements of their capabilities to organize and execute courses of action required to attain designated type of performance.' When one believes in one's own ability to be successful in a task, the person has a high self-efficacy. People with high self-efficacy are expected to do better in goal-setting and maintain a strong focus on the challenges they face. On the contrary, people with low self-efficacy perceive tasks to be difficult and would expect a failure. Self-efficacy is central to the social cognitive theory (Schunk & Pajares, 2009) in determining one's decision in the face of difficulties in a task. Self-efficacy is different from self-confidence. According to Bandura (1997), confidence is a nondescript term which shows a person's strength of belief. It is not necessary to specify what the belief is about. However, self-efficacy is different in that it shows one's belief in his or her own capability. Self-efficacy is built and sustained upon four factors, namely mastery experience, vicarious experience, social persuasion and emotional arousal (Bandura, 1994, 1997; Pajares, 2002).

Mastery experience or performance is the most influencing factor of self-efficacy. Schunk, Meece and Pintrich (2014) pointed out that any gain in self-efficacy would not be long-lasting without the support of success in performance. Moreover, an increase in self-efficacy could motivate students to reflect upon their learning to make further improvement by refining their skills.

Another factor of self-efficacy is vicarious experience. Vicarious experience could be described as the observation made by a person towards people who were undergoing similar tasks. The result could be positive or negative depending on the object or model being observed. Such explanation predicts a gain in self-efficacy when a person observes someone successfully attains a goal, and conversely, it would predict a loss in self-efficacy when the object being observed fails. It is particular important in the context of education because students in a class could have very similar goals, and hence vicarious experience could affect the morale of the class. Schraw and colleagues (2006) shared similar ideas as Schunk and Meece (2006) that students' self-efficacy could be improved when students observe models of similar ability in their class.

The third factor influencing self-efficacy is social persuasion, also referred to as verbal persuasion, depending whether a learner is verbally persuaded to do a task. Bandura (1994) pointed out that students tended to give up easily when their abilities in doing such task were disagreed upon. On the contrary, praises to students in a realistic manner could exert a positive effect on their self-efficacy.

The last factor contributing to self-efficacy is emotional arousal, also known as physiological arousal. This factor mainly depends on the psychological condition as influenced by one's physical state and emotional state (Bandura, 1997). Negative emotional arousal is related to fatigue, illness and stress, which could cause a loss in self-efficacy. In summary, self-efficacy of students is positively linked to mastery experience, vicarious experience and social persuasion. In contrast, emotional arousal could pose a negative effect on students' self-efficacy. Students with high self-efficacy are likely to aim at higher goals. They are also more capable of facing challenges and difficulties. They would also exert higher effort by using different learning strategies in task accomplishment (Bandura, 1986; Goddard, Hoy & Woolfolk Hoy, 2004).

2.3.1 Self-efficacy and science education

Different studies have shown self-efficacy as a powerful predictor in science academic achievement (Ridlo & Lutfiya, 2017; Kiran & Sungur, 2012; Cheung, 2014; Sadi & Uyar, 2013; Peters & Kitsantas, 2010; Zepeda et al., 2015; Gonzalez, Fernandez & Paoloni, 2017; Britner, 2008; Sawtelle et al., 2012). As most students studied more than one science subject, quite commonly they would apply 'common learning strategies' across different science subjects like chemistry and physics, or even mathematics. Zeyer (2018) labelled Biology as a 'life science' subject of complex systems while physics and chemistry as 'hard sciences' of ordered systems. They are meant to be taught in different teaching style. Failure would be expected because these 'common learning strategies' may not be applicable to biology. They could wrongly attribute their poor results to the difficulties of biology itself, or to their low intelligence, but not their poor choices of learning strategies. To avoid such scenarios to recur, teachers should help students attribute their failure in a way that would foster improvement and motivation. Poor behaviors of student can be expected in boring cycles of poor results and repeating recitation exercises. Many students in Hong Kong study biology without an aim to gain thorough understanding of the concepts involved because they think that recitation is important to obtain good results in biology examinations in an examination-oriented culture in Hong Kong. The low motivation can be explained by social cognitive theory (Bandura, 2000). In social cognitive theory, there are three major components, namely personal factors, environmental factors and behaviors. Self-efficacy is a core component of the personal factors as it reflects a person's belief in his/her own ability to reach the desired level in his/her assessment. Bandura (1994) also told the importance of self-efficacy in shaping the way that a person thinks about themselves. This echoed the study of Schunk and Pajares (2009) that high self-efficacy can improve students' persistence in their journey of learning.

Lin and Tsai (2013) proposed that different levels of conceptions of learning in science could lead to difference in students' self-efficacy. Conceptions of learning, ranging from low-level including memorization and calculation, to high-level including understanding, application, and seeing the knowledge in a new way. Eventually the students would gain higher confidence in learning, which in turn would lead to a higher self-efficacy in learning. A survey on students' self-efficacy could provide important information to science educators. Having said that, Cheung (2015) pointed out a lack of research about self-efficacy in a real science classroom setting. He conducted a study to assess students' self-efficacy in a Hong Kong chemistry class. He defined science self-efficacy as students' beliefs of their own ability to perform required action in scientific problems. His study demonstrated that deep learning strategies (Entwistle & McCune, 2004), which includes metacognitive control strategies (Pintrich et al., 1991) had exerted a direct effect on students' chemistry self-efficacy. This finding could provide a basis for designing teaching to enhance self-efficacy in Biology learning in Hong Kong.

2.3.2 Self-efficacy and metacognition

Different scholars agreed that self-efficacy and metacognition are positively correlated. Koseoglu and Efendioglu (2015) pointed out that students participating in the learning processes actively and receiving feedback on their performance continuously display a higher self-confidence and attach a greater value to their learning. Zhang (2003) argued that students with greater self-efficacy can perform better because they can cope with cognitive demands better. Cera, Mancini and Antonietti (2013) found that constructs which are related to self-efficacy, such as academic anxiety, use of strategies, task values and interests are closely related to metacognition in their discussion of the relationship between metacognition and self-efficacy. Moreover, a key finding by Crede and

Philips (2001) indicates that students with a higher level of metacognition would view academic study more importantly, who would then demonstrate higher levels of self-efficacy with the use of more effective learning strategies. Buehl and Alexander (2001) and Gonzalez et al. (2017) conducted studies to explore the relationship between students' self-efficacy and metacognitive planning, monitoring and evaluation. Both of their studies found out that students with a higher level of self-efficacy could plan, monitor and evaluate to a greater extent, which leads to better performance. These echoed Sungur's (2007) and Pintrich et al.'s (1993) studies that students with higher self-efficacy tend to regulate their effort and cognition by applying different strategies. Linnenbrink and Pintrich (2003) also supported the role of self-efficacy in students' behavioral, cognitive and motivational engagement. In conclusion, students' learning outcome could be affected by self-efficacy and metacognition. Students with a higher metacognitive regulation and self-efficacy are likely to be more self-regulated. Such interaction could foster higher confidence in students' abilities or self-efficacy when they are given challenging tasks to work on.

2.3.3 Self-efficacy and anxiety

Cimen and Yilmaz (2015) reported that students' biology self-efficacy could be strongly related to students' biology anxiety and past experience. On the contrary, a higher anxiety could lead to a higher emotional arousal and physiological state, which could lower students' self-efficacy (Bandura, 1994; Usher & Pajares, 2006). A recent report by Gonzalez, Fernandez, and Paoloni (2016) discussed the importance of the relationship of self-efficacy and metacognition with such academic emotion. In their study with 520 students in physics, they aimed to investigate into the relationship between them in science education. The main findings of their study were (1) self-efficacy reduced anxiety and (2) metacognitive strategies positively predicted performance. For

(1), they suggested that students with high self-efficacy would plan, monitor and evaluate their learning to a larger degree with a lowered level of anxiety. In a study on the effect of open inquiry process on students' motivation in a challenging education process, Adler and colleagues (2018) suggested the lowered anxiety amid a more challenging task was the result of teachers' emotional support and a shift of teachers' role, leading to higher students' motivation.

2.4 SSI as a vehicle to improve self-efficacy and metacognition

In a meta-analysis on the different approaches in implementing metacognition in science education conducted by Avargil and colleagues (2018), they cited Choi and colleagues' study (2011) about the five dimensions of global scientific literacy for the 21st century. One of the five dimensions, namely 'metacognition and self-direction' which is the ability to regulate one's thoughts through metacognitive planning, monitoring and evaluation, drew the attention of the researchers. Their study revealed that current science education often omits the importance of metacognition, problem-solving skills development with authentic examples and scientific issues. By contextualizing learning in SSI, students could gain more understanding of the work of real-life scientists and science-related careers through the learning process. As mentioned by Choi and colleagues (2011), not only scientists, but also citizens in the 21st century should be able to build their arguments on sufficient scientific evidence.

As discussed before, Hong Kong students have good scientific literacy compared to students in other regions. However, their performance in PISA were found to be dropped when compared to the previous cycles. The overall lower score was affected by a relatively lower scores on science competency subscales under the science literacy assessment. Science competency subscales included interpreting data and evidence scientifically (OECD, 2017, p.21). In order to enhance Hong Kong students' learning in science, we could consider using SSI to emphasize the building of students' skills in identifying questions and drawing conclusions on the basis of evidence. This could be achieved through leading students to learn and reflect in a metacognitive way. As informed by literature, through an explicit metacognitive-rich inquiry approach (Tanner, 2015; Seraphin et al., 2012), which involves instructing students directly and explicitly metacognitive strategies, students are likely to develop better understanding of the topic and how knowledge claims are justified, and to achieve better knowledge retention. Gunstone and Mitchell (1998) and Mason (1994) also supported that such explicit instruction could lead to improvement of metacognition in a classroom.

Apart from the curriculum design, incorporating SSI into classroom learning could help address students' low motivation towards learning biology by enhancing their self-efficacy. As discussed therein, self-efficacy reflects a person's own ability to reach the desired level in their assessment. Bandura (1994) argued for the importance of self-efficacy in shaping the way that a person thinks about themselves, which is supported by Schunk and Pajares's (2009) study that self-efficacy can improve students' persistence in their journey of learning. As further elaborated by Cera, Mancini and Antonietti (2013), metacognitive skills or self-efficacy alone might not be sufficient to guarantee satisfactory learning outcome and drive students to be self-regulated. As illustrated by Latham and Locke (1990), students with high self-efficacy would opt to work hard and accept challenging tasks. At the same time, those students would overcome obstacles by exercising their ability and strategies to the full (Prat-Sala & Redford, 2010).

As SSI could help set biology learning in a context familiar to students, SSI education has potential for lowering the barrier for students to acquire mastery experience, hence improving their self-efficacy. In a study conducted by Aydin (2015) to investigate high school students' self-efficacy, self-efficacy was shown to have a strong correlation with the use of metacognitive strategies and intrinsic motivation. This finding is consistent with the study by Coutinho (2008) on the correlation between metacognitive awareness and self-efficacy, and with the idea of Kanfer, Ackermann and Schmitt (1989) that efficacious learners use metacognitive strategies. Thus, if SSI can provide an activity context that could develop students' metacognitive ability, they may also provide a fertile ground for developing students' self-efficacy.

Despite these, the potential of SSI approaches embedded with metacognitive activities in promoting self-efficacy, and hence motivation in learning biology, are not extensively studied, let alone in Hong Kong context in relation to biology learning. The findings of such study may provide new insights into ways to address problems of biology learning that have persisted in Hong Kong schools, and among boys in particular. As discussed therein, evidences from different researchers showed that a high metacognitive ability is related to effective learning and enhanced self-efficacy. It is thus worthy of exploring whether the use of an SSI approach, enriched by explicit metacognitive-oriented instruction, could enhance students' conceptual learning in biology.

2.5 Explicit delivery of metacognitive knowledge

Pintrich (2002) discussed the importance of teaching metacognitive knowledge in classroom. Students who know different strategies are more likely to use them. And if students do not know the strategy, they cannot use it. Explicitly teaching of metacognitive knowledge could address their difficulties in coping with cognitive demands.

Tanner (2012) discussed ways of promoting students' metacognition. Expanding from Flavell's (1979) definition of metacognition, she emphasized the importance of planning, monitoring and evaluating own learning processes in an inquiry setting. She suggested that teaching students to think and learn in the way that real life biologists could use to integrate concepts across different levels of organization and complexity. In her study, undergraduate students were explicitly taught for metacognitive skills. This guided students to learn and think like real biologists. She emphasized the importance of the classroom learning environment with metacognitive strategies embedded in achieving such aim. In her design of metacognitive-oriented biology classroom, students had to assess their current thinking about the understanding of topics before the start of the course. Students then identified their confusions in a science classroom by using Muddiest Point strategy (Angelo & Cross, 1993) to direct them explicitly to identify their confusions with the instructors and fellow students. Lastly students assessed their learning by going through a retrospective post-assessment to recall their learning in the topic and reflect on their own learning through self-questioning.

Along this line, Stanton and colleagues (2015) suggested the use of metacognition assignment such as examination preparation and post-examination tasks to guide students to develop metacognition knowledge and encourage metacognitive regulation. Students were guided to plan, monitor and evaluate their learning strategies in studying. In their study, half of the students monitored their learning strategies and gained better understanding of the task. They also realized they needed more materials and exposure to the contents which could help them plan better. The remaining half of the students could not monitor their learning and gave ambiguous attributes to unsatisfactory strategies used. These researchers did not find their results surprising because monitoring skills were more difficult to develop (Schraw, 1998; Pressley & Ghatala, 1990; Alexander et al., 1995). Based on their outcome that students had different engagement levels in metacognitive regulation (planning, monitoring and evaluation), the researchers hypothesized that some learners might not have benefited from metacognitive regulation because of a lack of metacognitive knowledge for the most-struggled students and a lack of procedural knowledge for the less-struggled students. As metacognitive regulation is an important part of self-regulated learning (Zimmerman, 1986; Schraw, Crippen & Hartley, 2006), developing key metacognitive regulation strategies (planning, monitoring and evaluation) (Jacobs & Paris, 1987; Schraw & Moshman, 1995) is believed to be a key to students' success.

The above findings call for a need to couple SSI with explicit delivery of metacognition knowledge so that learning through SSI in the classroom could be benefited from the development of metacognition (Pesut & Herman, 1992; Spence, Yore & William, 1999, Seraphin et al., 2012; Kruit et al., 2018; Pottenger et al., 2007; Seraphin & Baumgartner, 2010). Seraphin and colleagues (2012) found that such inquiry-based learning could be linked to metacognitive abilities, and explicit teaching of metacognitive strategies could potentially promote the teaching of science. In a study conducted by Spence, Yore & Williams (1999) examining the effects of explicit science reading instruction on students' metacognition, significant improvement in students' metacognition and the ability to comprehend science readings were obtained. Such effect might be related to the enhancement of students' ability in information processing. As for the development of self-efficacy, Nota, Soresi and Zimmerman (2004) described how self-efficacy could influence learning by changing the information processing process. They believed that information processing within a person's cognition could affect the learning process. A student would perceive a task to be difficult and influential to his or her information processing when self-efficacy is not sufficient.

2.6 Proposed significance of a metacognitive-rich SSI approach

By contextualizing learning through SSI, students could have more understanding towards real life biologists and biology-related careers through inquiry learning processes contextualized by SSI. However, the potential of SSI approaches embedded with metacognitive activities in promoting self-efficacy and motivation in learning biology are not extensively studied.

Different researchers made different uses of SSI in science education to achieve their desired research outcomes. It is generally agreed that SSI can be utilized as a mean focused more on argumentation, informal reasoning and decision making of students (Topcu, Mugaloglu & Guven, 2014; Lee, 2007). Many of the researches in SSI focus on the development of argumentation. However, the effect of such approach could be hindered by the ability of the teacher to use argumentation and the cognitive demands on teachers and students. As discussed earlier, the acquisition of metacognitive skills is essential to promote argumentation and informal reasoning in SSI education. SSI discourse brings together cognitive, social, moral and emotional aspects of informal reasoning to reach an informed judgment on the SSI, hence it has a potential to promote metacognitive strategies, which involve self-evaluation.

In a study by Ozturk (2011), the relationship between metacognition and informal reasoning was discussed in the context of the issue of nuclear power plant construction. The study, which involved 674 pre-service science teachers, reported a significant correlation between metacognition and informal reasoning. Yet, with limited number of research studies investigating the relationship between metacognition and informal reasoning, such relationship remained unclear. Moreover, although there have been ample evidence showing the benefits that SSI could bring to science education. SSI could be complex, and students could be distracted while working through the SSI. In a recent study, Adler and colleagues (2018) revealed the importance of embedding metacognitive support within their framework on science inquiry. They provided support to students' metacognitive knowledge and regulation by using a strategy evaluation matrix to promote students' metacognitive knowledge. At the same time, they applied the regulatory checklist (Schraw, 1998) and the reflective metacognitive questions (Mevarech & Kramarski, 1997, 2006; Zion, Michalsky & Mevaerch, 2005) to ensure students to control their learning through explicit directions.

Despite this, the potential of incorporating metacognitive strategies in the context of SSI should not be undermined, but the coupling of metacognitive-rich strategies with SSI design needs careful consideration. Hogan (1999, p.1101) pointed out that simple immersion of metacognitive guidance might not be sufficient to build up students' metacognition. Thomas (2013) argued the importance of reasoning strategies and explanations from teachers in fostering students' metacognition. Cera, Mancini and Antonietti (2013) described metacognitive ability as an awareness and control over information acquisition, processes and storing for cognition. Students who make use of such skills could be benefited from the nature of metacognition that supports reading and writing, eventually assisting them in conception recitation and learning reflection.

To further enhance learning experience in class, Littrell-Baez and colleagues (2015) proposed the use of retrieval practice to improve metacognitive skills of students. This study utilized their suggestion of employing challenging questions that require students to construct response from memory. Spellman and colleagues (2016) summarized common examples of metacognitive learning activities in the ecology classroom. Among these examples, 'reflective reading' could trigger students to read with guided metacognitive questions. They conducted a 6-week ecology intervention and assessed the effectiveness of daily metacognitive learning strategies instruction on the improvement of students' metacognitive ability. In their study, they administered the 'metacognitive learning cycle' proposed by Blank (2000). The characteristic of such cycle is that there are explicit metacognitive checks in between. Blank (2000) reported a long-term improvement in students' metacognitive ability, which is consistent with the findings of other studies (e.g., Blank, 2000; Thomas & McRobbie, 2001; Dignath & Buttner, 2008). This points to the potential for designing ME-rich SSI to enhance metacognition in the context of SSI. Metacognitive guidance may in turn enable students to select appropriate strategies in decision making, hence making better decision (Chiu, Chen & Linn, 2013). This was supported by a conclusion made by Colombo, Iannello and Antonietti (2010) that metacognitive questioning and reflection could help students re-consider the validity of their decisions. In their study, students faced regret after a failure in decision-making which could show the emotional aspects of metacognition which was discussed earlier (Efklides, 2006, 2011). Such mistake could lead to a loss in self-efficacy. Their study showed how the cognitive and affective aspects of metacognition might interact to influence decision-making among students.

Motivation and cognition are very important in predicting students' academic performance (Pintrich, 1988, 1989). SSI have potential for motivating students to learn by promoting students' interests. Dori and colleagues (2003) conducted a study on students' interests in an SSI-based learning environment. They claimed that the controversial nature of SSI is important in building students' interests because they could actively link science to social problems. Coupled with the explicit teaching of metacognitive knowledge to help students cope with the cognitive demands of learning biology, students' anxiety is expected to be lowered. With a higher ability to cope with high cognitive demand, students with lower self-efficacy may be able to perform better. This could hopefully lead to a cyclical process of developing students' metacognition and self-efficacy in facing challenges brought about by cognitively demanding learning tasks in an SSI.

To achieve this, there should also be a concomitant change in the role of the teacher in the lesson. Gioka (2007) argued that science teachers should play the roles of promoting discourse by providing feedback and setting more intellectually demanding tasks to students. To facilitate this role shifting, the SSI approach can be adapted to deliver more quality and challenging tasks to students so as to promote their metacognitive skills towards biology. Such approach will have to embrace activities to advance students beyond contextual understanding to cognitive understanding, and finally to metacognitive understanding. Utilizing SSI could allow teachers to give continuous feedback to students with the use of mind map and concept map in classroom.

This could encourage students to attribute their failure to their learning strategies through the process of metacognitive regulation. Focusing on the explicit instruction of metacognitive strategies under the SRL model, a design of an SSI approach with strategies for developing metacognition embedded was proposed in this thesis. The study aims to investigate into the impact of this modified SSI approach on male biology students' metacognitive regulation and self-efficacy, and the relationship between these two attributes. The findings of such study would hopefully provide new insights into ways to improve biology learning in Hong Kong particularly for male students.

2.7 Conceptual framework of a metacognitive-rich SSI approach

This conceptual framework is a fusion of Presley and colleagues' SSI framework (2013) and the self-regulation and Zimmerman and Moylan's cyclical phase model of self-regulated learning adapted by Zepeda and colleagues (2015). It postulates the effect of an intervention by the aforementioned ME-rich SSI approach in a Hong Kong ecology classroom. The researcher made use of explicit instructions of metacognitive knowledge and regulation in his biology classroom. Such explicit instruction is believed to boost students' metacognitive regulation. With a higher metacognitive regulation, a student could develop his self-efficacy from different sources including mastery experience made possible by the SSI-based classroom environment. As metacognition and self-efficacy are core to the framework of SRL, they are hypothesized to work in synergy to uplift students' conceptual understanding of ecological knowledge. Based on this theoretical and conceptual framework, this study aims to study the effects of the SSI-based approach on the key variables depicted in this framework and their possible interrelationship in an ME-rich SSI-based learning environment. The framework of this study is summarized in the figure on the next page (Figure 4).

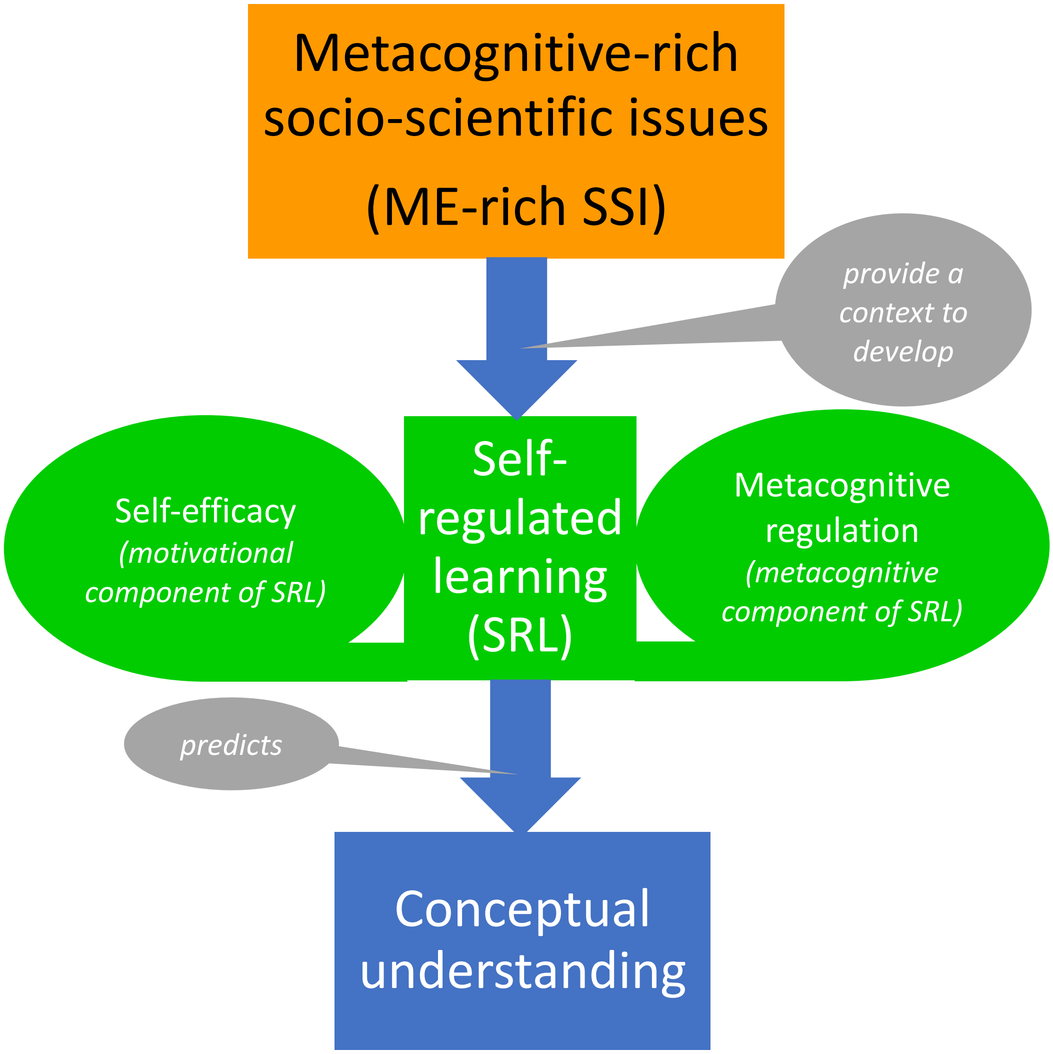

Figure 4. Conceptual framework of the study: Utilizing an ME-rich SSI approach to promote learning in biology

2.8 Summary of the literature review

SSI are believed to achieve various learning outcomes in science education. In an SSI-based classroom with rich discourses and evidence-based scientific argumentation, the cognitive and metacognitive abilities of students are expected to be developed in students as informed by literature. Students' metacognitive regulation, namely planning, monitoring and evaluation could provide appropriate strategies to tackle challenges in the learning journey. The affective dimension of self-regulated learning has been shown to be closely related to the self-concept and motivation of a student. As one's self-regulatory learning strategies are largely affected by one's self-efficacy (Pintrich & De Groot, 1990), the sources and development of students' self-efficacy should not be overlooked. To drive students to be self-regulated learners, metacognitive skills and self-efficacy are equally important (Cera, Mancini & Antonietti, 2013). The possibility of an SSI-based education to promote these two vital students' attributes in science education could be an answer to the call from science education policy makers to promote our next generation's science literacy and competency in the 21st century.

Chapter 3: Methodology

3.1 Subjects and setting

The sample for this study consisted of 54 male students from St. Paul's College, a boys' school in Hong Kong. They all chose biology as one of their elective subjects for the Hong Kong Diploma of Secondary Education Examination (HKDSE). They were all taught by the researcher, and their abilities were comparable. In this study, the topic 'Applied Ecology' was selected for intervention. The intervention group was taught with the ME-rich SSI approach, while the control group received conventional teaching methods without incorporation of metacognitive tasks.

Applied Ecology is one of the four electives in the HKDSE Biology curriculum. In this topic, students will build on their prior knowledge of basic ecological principles to develop further understanding of applied ecology. Students will explore some of the ways in which human activities can impose far-reaching effects on the environment. Local and global pollution issues, resources management, pollution control measures and conservation will be also discussed. At the end, students are expected to apply a range of field study skills to investigate the impact of pollution on the local environment. Applied Ecology builds on students' prior knowledge of the Diversity of life forms, Essential life processes, Ecosystems and Health and Diseases studied in the compulsory part (Curriculum Development Council & Hong Kong Examinations and Assessment Authority, 2015). Management of natural resources and pollution have been reported as an environmental SSI by Zeidler and Kahn (2014). Rickinson's team (2004) and Dillon's team (2009) conducted a summary report on experiential field-based learning and such experiential learning were shown to induce improvement to different learning outcomes in the aspects of cognition and affection.

3.1.1 St. Paul's College

Founded in 1851, St. Paul's College is the oldest secondary school to commence operation in Hong Kong. There are six classes at each level from form one to form 6 respectively. The medium of instruction of the college is English. Under the New Senior Secondary education structure, senior form students can choose elective subjects in which they would like to specialize. In this study, all the 54 students chose biology as one of their elective subjects.

3.1.2 Context of Hong Kong

After 1997, Hong Kong became a Special Administrative Region of the People Republic of China. Hong Kong citizens have been used to express their views towards social issues due to the freedom of speech guaranteed by the Central Government as an important manifestation of the 'One Country, Two Systems'. With the implementation of the new senior secondary curriculum in 2009, Liberal Studies has become a new core subject for senior secondary students. They were expected to view issues from multiple perspectives. At the same time, science education was restructured to embrace more scientific inquiry, and teachers are also expected to teach the ideas of the nature of science (NOS) and the inter-connections of STSE (Lee, 2017).

3.2 Research design

Two biology classes (A and B) of grade 12 boys aged from 16-18 were involved in this investigation of the effectiveness of using ME-rich SSI approach in the teaching of biology. The class size of the two classes A and B were 31 and 23. Hence, a total of about 54 grade-12 male students were involved in the research.

Based on the framework developed to guide this study (fig. 4), the researchers adopted a quasi-experiment design to investigate into the possible causal relationships embedded in the framework, i.e. among metacognitive regulation, self-efficacy and conceptual understanding. Creswell (2012) mentioned in his guide in educational research that an experiment should be used to establish possible causes and effects between independent and dependent variables. Experimental research with a psychological focus first began in early 20th century with psychological experiments. As mentioned by Pressley and colleagues (2006), many educational interventions were inspired by different theories about learning, cognition and motivation. Educational intervention researchers used different research methods, including true experiments and quasi-experiments. True experiments, which are the most rigorous, involved random assignment of individuals to treatment and control groups. Without this randomization as in the case of intact groups, the study would become a quasi-experiment, which is subjected to greater threats to validity and representativeness.

Quasi-experimental designs could potentially be biased, delivering larger intervention effects than true experiments (Cook & Campbell, 1979). Before adopting the quasi-experimental design, the researcher had to consider the potential threats and keep selection factors minimal in choosing the two groups. However, as in many educational researches, randomization of individuals is not possible. Hence, the importance of quasi-experimental designs should not be undermined. Intact groups would need to be used as it is generally impossible to create groups of students by randomization which would disrupt class setting and school timetabling. Therefore, this study adopted a quasi-experimental approach utilizing existing groups (classes).

Another approach used in education research that involves interventions is the within-group or pre-experimental designs. This approach does not require dividing the sample into the treatment and control groups. These designs were used when there are limited participants so that grouping is impossible. This kind of designs made use of repeated measures of the dependent variable applied to a single group. This type of deign includes time series and repeated measures (Creswell, 2012).

Although this type of design does not suffer from the same threats to validity as quasi-experimental designs, it could not establish any causal relationship between the intervention and the dependent variable without referencing to a control group. This is because any changes to that single group could be the result of any change that took place concurrently with the intended intervention, which might not be known to the researcher. Hence, this may lead to erroneous conclusions about the effectiveness brought about by the intervention (Institute of Education Sciences, Washington, DC, 2003).

Moreover, compared to experimental designs, studies of with-in group or subject could be affected by the maturation of participants due to the length of data collection (Creswell, 2012). In a study using multiple treatments in particular, the validity of the study could be less convincing due to the history of each treatment among individuals as the previous treatment could affect the following treatment in repeated measurements. Due to all of the above considerations, this study adopted the quasi-experimental design.

According to the guide to educational research published by the U.S. Institute of Education Sciences, Washington, DC (2003), the two groups of students should be matched in terms of (i) prior test scores or academic achievement, (ii) demographic characteristics, (iii) time period in which the two groups are studied, and (iv) methods used to collect data.

In this study, students' metacognitive regulation, self-efficacy and conceptual understanding were first compared by pre-tests to ensure that there were no statistical differences between both groups before the intervention. The two groups were of comparable academic ability. Hence the effect due to difference in ability level was minimized. All the students participated were ethnic Chinese. As it is a boy school, the sample consisted of a single gender. The two classes were taught by the same teacher (who is also the researcher) so as to minimize the effect of teachers' experience and style. Both classes were of grade 12, and the time period in which the two groups were studied were kept the same. Lastly, the instruments used in pretest and posttest assessments were exactly identical. The above considerations could ensure the intervention and comparison groups were closely matched prior to and during the intervention.

In this study, two intact classes were involved in this study. These two classes were assigned into the intervention and control groups. Such assignment of student group was by random. The rationale underlying this research was to investigate into the low motivation and interests of boys in biology learning. After a random assignment of the intervention and control group, 31 students from class A were assigned to the intervention group to receive the intervention of the ME-rich SSI, while the other 23 students from class B was treated as the control group and received conventional teaching for comparison sake.

3.3 Ethical considerations

Creswell (2012, p.326) argued that ethical issues in experimental research relate to withholding the experimental treatment from some individuals who, hence, might not be able to benefit from it. However, on the other hand, whether or not the adopted experimental design could provide positive answer to the research question could also give rise to ethical issues. Hammersley and Traianou (2012) discussed thoroughly the ethical considerations that educational researcher should be aware of. Those ethical principles included minimizing harm, respecting autonomy, protecting privacy, offering reciprocity, and treating people equitably.

In this study, the researcher believed that a metacognitive-rich SSI might bring possible benefits to the both learning and development of students. However, the outcomes might not be turned out as intended. In this sense, the researcher integrated the intervention with the conventional curriculum so as to minimize disruption to normal teaching given the tight curriculum schedule for high school biology, while ensuring students of both groups developed the basic conceptual understanding as required for certification. The intervention was 3-week long, which was the same as the treatment received by the control group. In this way, the learning progress of the intervention group as well as the control group would not be jeopardized in case of unpredicted consequences brought about by the research design. To respect students' autonomy, the researcher announced to students in the intervention group that they had the right to choose to participate or return to the normal approach. They were informed no adverse consequences would be imposed onto them if they chose not to participate in the intervention activities, pretests, posttests or the post-lesson interviews. Consent forms were signed by students before conducting the interviews. To protect students' privacy, the researcher kept all students' data in strict confidence, and used randomized number in reporting students' vignettes in the post-lesson interviews. Lastly, students were given opportunities to ask the researcher questions about the purpose of the research and how the data would be handled and used. All the students in both intervention and control groups were treated equally without discrimination.

3.4 Intervention of ME-rich SSI

A teaching intervention process based on SSI was designed to create a metacognitive-rich inquiry-based learning environment for students to learn specific biology topics. This learning environment or approach is termed metacognitive-rich SSI (ME-rich SSI). This study adopted the framework of Presley and colleagues (2013) about SSI-based education as detailed in Figure 1 in Chapter 2. The framework consists of three core elements including the 'Design Elements', 'Learner Experiences' and 'Teacher Attributes' situated in the 'classroom environment' and subjected to 'peripheral influences'.

3.4.1 Design elements

In the lesson, students in the intervention group will be given a social issue which has a strong relationship with science – sustainable development in Hong Kong. As noted by Presley and colleagues (2013), the issue must be presented at the beginning of instruction so as to introduce the issues at the initial stage to deliver the essential contents to students. As mentioned by Sadler (2011), delivering authentic examples in context could facilitate students' understanding and skills development outside school. Moreover, a teacher should provide scaffolding to students to facilitate higher order thinking, including argumentation, reasoning and decision-making so as to support students to analyze the issues concerned from multiple perspectives while at the same time working out the students' own stance. Although argumentation, reasoning and decision-making were not the main foci of this study, students in the intervention group must obtain related experience to fulfil the requirement of this framework, and adequate information about the SSI being discussed in the lesson. Students had access to opposing ideas either for or against controversial issues with evidences in support of different claims from the newspaper clip and students are required to complete the tasks involving stance taking and critique of opposite stances. Given that Hong Kong grade 12 students have received some training on argumentation in the Liberal Studies subject (a core subject of new senior secondary curriculum in Hong Kong), students are assumed to be able to demonstrate such higher order thinking.

The last design element engaged students in accessing their prior knowledge and making connections with the issues through various activities including debates and projects. Drawing on the suggestions from Presley and his colleagues (2013), the researcher made use of mass media, including newspaper articles and television programs to link the ecology classroom with the outside world so as to allow students to explore a rich diversity of authentic information. The whole teaching and learning process involved preparation, data manipulation and data analysis. To minimize novelty effect, pilot interventions for students of the intervention group and control group were done using 'Human Reproduction' and 'Stem cell therapy' as the SSI contexts when they were in grade 11 the year before.

The socio-scientific issue – 'Is Tai Po district a successful example of sustainable development?' was selected to be implemented in the main study. Students received a set of teaching and learning materials which included different examples of habitats and biodiversity in Tai Po, Hong Kong.

The human impacts on the renewable, non-renewable resources, biodiversity and ecosystem in Tai Po were discussed using a variety of scientific information from television programs, newspaper articles, government's reports and academic journals. For the control group, students received the teaching and learning materials with similar content as that of the intervention group. However, all the materials about the issues discussed in the topics have been postponed to the end of the learning materials as references. Such design ensured that the students from both groups could receive the same concepts to be delivered from the textbook and their responses to the research instruments can be compared. The examples used in the intervention group included Lam Tsuen River, Kadoorie Farm and Botanic Garden, Tai Po Industrial Estate, Sam Mun Tsai fish culture zone, Sha Lo Tong, Fung Yuen, Artificial Reef in Tai Tan Hoi, Ting Kok and Lung Mei Beach. They were different places situated in Tai Po with different ecological significances.

3.4.2 Learner experiences

Another core part of this SSI-based education is the learner experience. Presley and colleagues (2013) suggested that students should be provided chances to engage in higher-order practices and confronting scientific ideas and social beliefs in the issue with the collection and analysis of scientific data and other evidences from multiple perspectives. Under such SSI setting in the classroom, a student would develop his own stance based on arguments through different activities, and be able to conduct his/her research, comparing his or her own finding with others to understand opposite views. Through the analysis of information sources from different perspectives, ranging from science to social, political and economic views, a student could understand the interaction between different perspectives in an SSI. Presley and colleagues' (2013) framework provides flexibility to allow additional learning experience. In their proposal, they suggest the inclusion of ethics and NOS as additional learning experiences. This study made use of such flexibility to include instruction on metacognitive strategies through explicit discussion of metacognitive knowledge and regulation (planning, monitoring and evaluation). Students were asked to discuss the controversies as revealed by the SSI and engaged in discussion to express their viewpoints in areas such as further legislation based on the evidences they collected.

3.4.3 Teacher attributes

Besides design elements and learner experiences, Presley and colleagues (2013) postulated teacher attributes as the final core element of the framework. A teacher should be familiar with the issues in both knowledge and awareness aspect. Moreover, a teacher should be humble to acknowledge himself or herself as a learner who would face knowledge limitation and contribute to knowledge building in the class. Lastly, he or she should be expected to face challenges and uncertainty in the SSI-based classroom. As the researcher himself would be the teacher of the class, this requirement should be assumed to be satisfied.

3.4.4 Classroom environment and peripheral influences

Though the classroom environment and peripheral influences are not core to the SSI-based education, they are important to the success of an SSI intervention. As suggested by Presley and colleagues (2013), the teacher of the classes have to be aware of students' emotion and willingness to discuss controversial issues. Given Liberal Studies as a core subject, Hong Kong students are presumed to be familiar with the discussion of controversial issues. They have adequate resources and skills to support their learning in issues at school and at home. Therefore, the requirement of the classroom environment and peripheral influences could be assumed to be satisfied.

3.5 Explicit instruction of metacognitive knowledge in ME-rich SSI

3.5.1 Pre-assessment of students' thinking (Assessment of thinking 1)

Before the start of the topic – the main issue – Is Tai Po district a successful example of sustainable development was introduced. After the introduction, students were asked to complete a table (Appendix F, p.1) about how they could plan, monitor and regulate their study in relation to the two objectives of the lesson. These two objectives were: (1) Understanding human impacts on the environment in Tai Po by industrialization and urbanization, and (2) Understanding human responsibilities in promoting sustainable development and conserving the habitats and organisms in Tai Po. Such design was inspired by Tanner (2012) in her study suggesting students should be asked to examine their thinking at the start point. It could help students think metacognitively and plan thoughtfully on how they could apply new learning strategies.

3.5.2 Mind mapping

After going through different information sources about Tai Po, students were given a mind map (Appendix F, p.5) with the central message – Human impacts on resources and habitat. Silver (2013) suggested that mind mapping would allow a thinker to capture the moment of reflection and metacognition by a visual-verbal way. This is a powerful technique to lead students to deeper thinking and promote self-regulation.

3.5.3 Video watching at home (Assessment of thinking 2)

Students were asked to do preparation work at home by watching a video about' Hong Kong fisheries'. To promote metacognition, students were asked to complete a table (Appendix F, p. 6) asking their planning, monitoring and evaluation of study strategies. They were also asked to take note of the concept of fisheries malpractices in Hong Kong.

3.5.4 Reading exercise 1: Thinking like a real scientist (1) Tai Po Industrial Estate

In this part, students were asked to answer questions identified from an article about the Fung Yuen Butterfly reserve which was being disturbed by human activities continuously. A map of the habitat of Fung Yuen and nearby areas was provided. Students were also provided with the readings: (1) Tai Po Industrial Estate and Reclaimed Land of the New Town, (2) Chemical Spill hits lab workers, and (3) Massive fish kill hits Tai Po fish culture zone. These readings were expected to provide students with authentic experiences that would lead them to think in real-world context and negotiate different stakeholders' views from a scientific point of view. They were then asked to state the benefits and harms arising from the development of Tai Po industrial estate as a manifestation of the controversial nature of SSI.

3.5.5 Explicit mid-point metacognition check

After the reading exercise, student was explicitly taught about the metacognition knowledge. Students were taught about the definition of metacognition. They were then asked to answer six questions about metacognition as follows:

(1) When I study for this class, did I pull together information from different sources?

(2) When I study the reading, did I outline the materials to help me?

(3) Did I question things I hear or I read?

(4) Did I miss important points in the lesson?

(5) In case of difficulties, did I change my strategies?

(6) Am I confident in doing well in this course?

The above questions were adapted and modified from the instrument 'The Motivational Strategies for Learning Questionnaire' which will be used in the quantitative study. These aimed to promote students' metacognition with critical thinking on their learning strategies.

3.5.6 Reading exercises 2: Thinking like a real scientist 2 - Eutrophication

Students were then asked to read a passage 'Stunning blue hue as algae lights up Hong Kong harbour'. Embedded in the reading, student had to answer 'Could you understand this passage? How does previous knowledge help you understand this?' They were given a 'challenge' to read a scientific publication titled 'A three-dimension eutrophication modelling in Tolo Harbour'. The aim was to provide students with authentic scientist's experience of reading diagrams, passages and charts about a learnt concept – eutrophication. There were given the challenge as accordance to the finding of Seraphin and colleagues' study (2012) that students' metacognition could be increased with intellectual-challenging tasks when students could be given chances to perform like real scientists in data manipulation.

3.5.7 Reading exercises 3: Thinking like a real scientist 3 - Afforestation

After a lecture presented by the teacher on the conservation of species and habitats, students were asked to read several pages of a Master of Science in Environmental Management Thesis. With regard to 'The status of natural successions in lowland secondary forests of Hong Kong', students had to answer the following metacognitive questions adapted and modified from Spellman and colleague's (2016) study.

(1) How do I comment on the usefulness of the above reading in learning this topic?

(2) Any prior knowledge I mastered? What are they?

(3) Any unmastered but learnt knowledge? What are they?

(4) Why did I forget some knowledge? How should I do?

(5) How do I comment on the style of learning in this topic?

3.5.8 Inquiry activity – Is Ting Kok development demonstrating sustainable development

Upon the completion of the syllabus, students were asked to make a group presentation on their assessment as to whether Ting Kok development is sustainable. Students were asked to reflect on their metacognition in their presentation. They were required to tell (1) ‘Were prior knowledge useful to you?’ (2) ‘How did you plan, monitor and regulate your learning in this demanding task?’; and (3) ‘Do you think this project help you in this topic? Why?’

After the presentation, students were assessed by the teacher on their independent thinking and communication skills as shown in the assessment form (Appendix F, p.36). They then received comments from the teacher. Their presentation was assessed by the teacher, after which they received the assessment form requiring them to further describe their changes in metacognitive regulation. Thomas (2003) referred the requirement for students to describe their metacognitive changes as metacognitive demands, which require students to think about how they learn science, solve science problem, think about difficulties in learning science, ways to become better learners of science and try new ways of learning science. In this case, students were required to give response to the teacher on the assessment form. At the end, they were asked to complete an essay about sustainable development of Tai Po without extra metacognitive demand.

3.6 The control group

In contrast to the intervention group, the control group received almost identical learning and teaching materials as the intervention group. The similarities and differences in treatment between the two groups were listed below:

Similarities:

1. There were almost identical learning and teaching materials.
2. Students in the control group were also required to conduct the inquiry activity upon the completion of the syllabus.
3. The mass media resources used by the teacher were made equally available to both groups with the following exceptions (listed under 'differences').

Differences:

For the control group,

1. There were no controversial issues stated at the beginning.
2. There were no metacognitive activities.
3. All the newspapers, television videos and other sources were removed from the main learning and teaching materials. A list of references is provided to students of the control group after teaching the topic.

The teacher in the control group did not focus on the student's role as knowledge contributor. Having said that, the teacher in the control group did not deliver the content knowledge in a didactic manner, but in accordance with the nature of the topic and the teacher's own teaching style. An outline of the flow of lessons in this study is summarized in figure 5 on the next page.

Week	Lesson	Topic	Intervention group (Using appendix F)	Control group (Using appendix G)
1	*1*	*Pretests*	*Pretests (Appendix A, B)*	
	2	*Applied Ecology and Tai Po district*	Introduction of socio-scientific issue: Is Tai Po district a successful example of sustainable development?	Introduction of Tai Po district. No introduction of socio-scientific issue.
			Pre-assessment of students' thinking (Assessment of thinking 1)	No pre-assessment of students' thinking
	3	*Resources and population growth*	Students were required to do mind mapping	Students were NOT required to do mind mapping
2	*1*	*The environmental impact of malpractices in fisheries*	Students were asked to watch the video about Hong Kong fisheries at home Students were asked to complete the task: Assessment of thinking 2	Teacher played the video about Hong Kong fisheries at class No assessment of thinking
	2	*The environmental impact of malpractices in agriculture*	Students read the Reading: Village Besides the River with the teacher in class	After teaching, teacher told the students to refer to the reading 1 for knowledge enrichment
	3	*The environment impact of industrialization and urbanization*	Students were required to go through the reading exercise 1: Thinking like a real scientist (1) Tai Po Industrial Estate	After teaching, teacher told the students to refer to the reading 2-5 and map 2 for knowledge enrichment
3	*1*	*Health problems related to air pollution*	Explicit mid-point metacognition check was done	After teaching, teacher told the students to refer to the reading 6 for knowledge enrichment. No explicit mid-point metacognition check was not done
	2	*Health problems related to water pollution*	Students were required to go through the reading exercise 2: Thinking like a real scientist (2) – Eutrophication	After teaching, teacher told the students to refer to the reading 7 and 8 for knowledge enrichment
	3	*Management of resources: Conservation*	After teaching, students were required to go through the reading exercises 3: Thinking like a real scientist (3) – Afforestation	After teaching, teacher told the students to refer to the reading 9 and 10 for knowledge enrichment
4		*Inquiry activity*	*Is Ting Kok development demonstrating sustainable development?*	
5	*1, 2*	*Group presentation*	Students were required to answer the additional question about metacognition.	Students were not required to answer the additional questions about metacognition.
	3	*Posttests and post-lesson interview*	*Posttests (Appendix A, B, C)*	
			Post-lesson interviews (Appendix D)	*No post-lesson interview*
6		*Essay writing*	*Is Tai Po district a successful example of sustainable development in balancing development and conservation?*	

Figure 5. Outline of the flow of lessons for the intervention and control group in this study

3.7 Variables in the study

The independent variable was the incorporation of ME-rich SSI in the selected topics.

The dependent variables under study are listed as follows:

1. Classroom environment: students' view towards the metacognitive-orientation of the classroom;
2. Students' metacognitive regulation before and after the intervention;
3. Students' self-efficacy before and after the intervention; and
4. Students' conceptual understanding before and after the intervention.

3.8 Mixed-method strategy

In this study, a mixed-method strategy was applied to yield answers to each of the research questions. In a broad sense, there are three approaches in the educational research, namely quantitative, qualitative and mixed methods (Creswell, 2009).

A mixed approach allows the researcher to collect both quantitative and qualitative data in a single study concurrently at the same time. Creswell (2009) argued that the use of either quantitative or qualitative methods could not provide a whole picture to address the complexity of an interdisciplinary research. He summarized the categories of mixed methods strategies, which include explanatory and exploratory, triangulation and nested, sequential or concurrent.

A combination of a questionnaire-based survey, interviews and assessment score analysis was applied in my study to obtain both quantitative and qualitative results. There were debates between the qualitative and quantitative methodologies regarding their significance to science education research (Szyjka, 2012). Salomon (1991) argued that qualitative and quantitative tools are compatible with each other instead of opposing each other. Eventually, such approach could lead to a more thorough understanding of the research and maximize the usefulness of the data collected in the process of making senses.

For qualitative methods, Glesne (2006) suggested that there is a need of applying a mixed approach so as to collect 'thick and rich' data for the study. In my study, questionnaires and interviews were used as the main quantitative and qualitative research tools. This aims to obtain more comprehensive data to explain how students learnt through the intervention which are important for evaluating students' changes in metacognitive regulation and self-efficacy (Feagin, Orum and Sjoberg, 1991).

3.9 Concurrent triangulation strategy

Considering different designs of mixed methods methodology, Creswell (2009) provided directions for researchers to consider before conducting the research. Researcher should consider timing, weighting, mixing and theorizing in designing the methodological framework for the study. Among the strategies suggested, the concurrent triangulation approach was adopted to structure this study owing to its nature to allow possible confirmation, disconfirmation, cross-validation or corroboration (Greene, Caracelli. & Graharn, 1989; Morgan, 1998; Steckler et al., 1992) by comparing and contrasting the quantitative and qualitative data collected. The quantitative and qualitative data could be weighed equally when addressing the questions in the research. The integration of the data was contemplated in the discussion section of this study, with the use of qualitative quotes to support or disconfirm the quantitative results.

3.10 Learning environment of the ME-rich SSI

Students' views about the metacognitive orientation of the classroom environment were assessed by applying the metacognitive orientation learning environment scale – science (MOLE-S) developed by Thomas (2002). Only the English part of the instrument were adapted and used. The main characteristics of a meta-cognitively oriented classroom included metacognitive demands, teachers' explanations and discourses. The data collected from MOLE-S, assessment was used to assess how far the intervention could create a metacognitive-rich learning environment from the students' perspective.

3.11 Quantitative data collection

The Motivational Strategies for Learning Questionnaire (MSLQ) and test of conceptual understanding were administered before and after the teaching of the ME-rich SSI so the changes of variables due to the intervention could be measured. These variables include students' self-efficacy, metacognitive regulation and conceptual understanding. The different instruments used for collecting these data were detailed in the next few sections.

3.11.1 Measurement of self-efficacy and metacognitive regulation quantitatively

For quantitative methods, the MSLQ was used to study the changes of the variables of self-efficacy and metacognition. In choosing the instrument for measuring students' self-efficacy and metacognitive regulation, the researcher considered different instruments available. The instruments considered included the Learning and Study Strategies Inventory (LASSI) developed by Weinstein, Palmer and Schulte (1987), the Self-Efficacy and Metacognition Learning Inventory—Science (SEMLI-S) (Thomas, Anderson & Nashon, 2008). Similar to the MSLQ, they are also self-report instruments to assess learning strategies, but the principles of their designs vary.

It should be noticed that the LASSI and MSLQ is different in the purpose of administration. LASSI assesses students' learning strategies at a general level while MSLQ considers motivation and cognition under the social-cognitive theoretical framework in which they are bounded dynamically and contextually. MSLQ has been widely administered in research of self-regulated learning where motivation and cognition interact closely. On the other hand, both MSLQ and SEMLI-S could address self-efficacy and metacognition within the construct of self-regulated learning.

However, MSLQ was preferred over the SEMLI-S in the consideration of their representativeness in SRL research. The MSLQ could gauge students' views on self-efficacy, cognitive and metacognitive strategies. Self-efficacy is a major determinant of students' motivation in a task. In the design of the MSLQ by Pintrich, different metacognitive learning strategies and the level of self-efficacy were assessed to determine the motivation of a learner. This fits with the expectancy-value model of motivation he suggested. Panadero (2017) highlighted the important role of Pintrich's MSLQ in the field of SRL researches. Pintrich was highly regarded as a pioneer researcher to relate motivation and cognition in SRL. MSLQ has been widely used across the world (Schunk, 2005; Moos and Ringdal, 2012), and has been cited more than three thousand times. By contrast, SEMLI-S, which was originally designed to address Hong Kong science education problem, though highly relevant to the constructs involved in this study, has been far less common in use. Moreover, MSLQ has 15 scales group into two major categories - motivation and cognitive scales. Its development was largely based on a social-cognitive view of motivation and learning strategies in which students actively deal with his or her own cognitions and beliefs in the learning process. MSLQ and its different versions, modified or translated, were broadly applied by different education researchers all over the world.

Liu and colleagues (2012) commented the MSLQ was useful and valid with satisfactory reliability. They tried to examine the psychometric properties of the MSLQ in Singapore. It was found that the MSLQ could be applied to males and females alike in terms of its factor form and structure (Liu et al., 2012).

In 1999, Rao and Sachs (1999) translated the MSLQ into Chinese version (MSLQ-Chinese Version). They conducted a confirmatory factor analysis involving 477 students in different Hong Kong secondary schools. Their results found that MSLQ-CV could produce compatible measurement in Hong Kong as it could accomplish in western countries. Based on that, Lee, Yin and Zhang (2010) developed a revised Chinese version of MSLQ (MSLQ-CV) and reported a wide use in Hong Kong by different researchers (Mok, Fan, & Pang, 2007; Sachs, Law, Chan & Rao, 2001).

In a study about metacognitive developmental patterns of Hong Kong primary and secondary school students, Mok, Fan and Pang (2007) applied the MSLQ in Hong Kong. When applying, the reverse-coded items were not included because researches often show that Hong Kong students might be confused with those reverse-coded items which could undermine the findings derived from the MSLQ (Rao, Moely, & Sachs, 2000; Rao & Sachs, 1999).

In order to assess students' self-efficacy and metacognitive regulation, the MSLQ used in this study was directly derived from the original version developed by Paul R. Pintrich and his colleagues (1991). As St. Paul's College is a school using English as medium of instruction, the MSLQ is written in English. The modified MSLQ has 28 items, each on a 7-point Likert scale from 1 (not true) to 7 (very true). The revised MSLQ comprises different scales for the measurement of self-efficacy and metacognition. In this study, question 5, 6, 12, 15, 20, 21, 29 and 31 from the scale 'self-efficacy' were chosen to assess the self-efficacy of students while questions 53, 62, 64, 67, 69, 81, 32, 42, 49, 63, 36, 41, 44, 54, 55, 56, 61, 76, 78, 79 from the scales 'cognitive and metacognitive strategies: *elaboration*', 'cognitive and metacognitive strategies: *organization*' and 'cognitive and metacognitive strategies: *metacognitive regulation*' were chosen to assess metacognitive regulation of students. The inclusion of the scales 'elaboration' and 'organization' aimed to assess students' application of elaboration and organization strategies during the intervention.

As discussed by Pintrich (2002), the role of metacognitive knowledge in learning, teaching and assessment, metacognitive knowledge includes knowledge of general strategies knowledge. Strategic knowledge includes different strategies that a student might use through his or her learning process. These strategies are mainly grouped into 'rehearsal', 'elaboration' and 'organizational' strategies (Weinstein & Mayer, 1986). The scale 'Rehearsal strategies' was not included due to its less effectiveness (Pintrich, 2002). 'Elaboration' strategies with various mnemonics, in contrast, are more effective to bring about better comprehension and learning. On the other hand, 'Organizational strategies' are believed to be important to allow students to make connections and linkage among different knowledge within the topic. Lastly, the inclusion of the scale of 'metacognitive self-regulation' could reflect all of the phases of 'planning', 'monitoring' and 'regulation' (Pintrich et al., 1991). The selection of questions excluded the reverse-coded items to avoid confusions among students as argued by Mok, Fan and Pang (2007).

3.11.2 Measurement of conceptual understanding

A test of conceptual understanding was used as pretest and posttest to assess students' conceptual understanding before and after the intervention, and any change resulted. The contents of the pretest and posttest were identical so as to compare students' conceptual understanding in a fair and valid manner. The test consisted of 15 multiple choice questions and 20 true-or-false questions. Each part of the test weighed 50% of the overall score. Students' conceptual understanding was then recorded on a 100-point scale. The gain or loss of score from the pretest to the posttest reflects changes in conceptual understanding. Moreover, the abilities of students in the intervention and control groups were compared based on the results of the pretest to confirm if the two groups of students were comparable in terms of academic ability.

3.12 Measurement of the learning outcome of SSI-based design, motivation, strategy use, self-efficacy and metacognition qualitatively

After the intervention, students' views on the ME-rich SSI, strategy use, motivation, metacognitive regulation and self-efficacy were collected by qualitative measures to supplement the quantitative data obtained from the questionnaires.

To achieve such goal, semi-structured interviews were conducted with all the 31 students in the intervention group. As the interviews aimed only to collect views about the implementation of ME-rich SSI from students in the intervention group to explain the possible underlying reasons for changes in metacognitive abilities and self-efficacy among them. The other 23 students from the control group were not included in the interview session. The structure of the interview contains 4 main questions. The questions are listed as follows:

(1) *'Can you tell me about your impression about the intervention? For example, which part impressed you the most? What activities you think that are most useful?'*

(2) *'Could you describe how did you regulate your learning strategies in completing different task? How did you deal with the difficulties you faced in the intervention?'*

(3) *'Did you do any evaluation or reflection upon the completion of task? How and why did you do that?'*

(4) *'How do you think whether the intervention increase or decrease your confidence in studying and understanding biology and facing the coming assessment?'*

Under this interview protocol, students' views on SSI-based education, strategy use, motivation, metacognitive regulation and self-efficacy were collected with spontaneous follow-up questions by the researcher who conducted the interviews. Combining the data collected both qualitatively and quantitatively, the effectiveness and difficulties of incorporating an ME-rich SSI-based approach in biology learning would be discussed.

Chapter 4: Data Analysis and Results

4.1 Data analysis

The purpose of the study was to study the potential of the ME-rich SSI approach on the enhancement in metacognitive regulation, self-efficacy and conceptual understanding. The purpose of this chapter is to report the result of the study. Statistical data analysis is presented in the following sections, including reliability, descriptive statistics, analysis of variance, correlation and findings for each research questions. Tables are double or single-spaced in an effort to keep the table on one page. There were 54 valid responses from students from the intervention and control groups. For the intervention group, the sample size was 31 while the control group had the sample size of 23.

4.1.1 Quantitative analysis

Data obtained were analyzed using the statistical software Statistical Package for the Social Science (SPSS), version 24. First, internal consistency reliability (Cronbach's Alpha) was used to check the reliability from the variable data in the MOLE-S and the MSLQ.

Second, an independent samples t-test was conducted on pretest score of the dependent variables, i.e. metacognitive regulation, self-efficacy and conceptual understanding of students from the two groups. This was to ensure there was no statistically significant difference in dependent variables at pretest between students from the intervention group and control group before conducting the 2x2 ANOVA analysis.

Third, a 2x2 mixed design analysis of variance (2x2 mixed design ANOVA) was run to determine differences among metacognitive regulation, self-efficacy and conceptual understanding between students from the intervention group and control groups, before and after the teaching. It was used to ascertain whether the changes in the dependent variables before and after the intervention and between the intervention and control groups are statistically significant. In this study, a 2x2 mixed ANOVA was conducted to show both the difference between groups (intervention or control) and within students (before and after intervention). Differences in repeated measurements of the dependent variables were shown before and after intervention in both groups.

Fourth, independent samples *t*-tests were run on the gain in scores on metacognitive regulation, self-efficacy and conceptual understanding. This address a criticism that the mixed-design ANOVA might, or might not provide proper analysis (Morgan et al., 2003). Morgan and colleagues (2003) suggested the use of the gain in score approach together with the independent-samples *t* test. Therefore, both the mixed ANOVA and independent samples *t*-test were conducted to avoid improper interpretation. The above measures could avoid any misleading results from the ANOVAs in the previous step.

Fifth, a one-way MANOVA was conducted with the two student groups as independent variables, and with the gain in scores in metacognitive regulation, self-efficacy and conceptual understanding as dependent variables. Lastly, Pearson correlation was performed on the gain of scores on the three dependent variables to check their correlation with each other.

4.1.2 Reliability of the instruments

A reliability analysis was carried out on each of the seven sections of the MOLE-S questionnaire, each comprising five items. These seven sections are metacognitive demand, student-student discourse, student-teacher discourse, student voice, distributed control, teacher encouragement and support and emotional support. Cronbach's alpha also indicated the reliability was acceptable, with α = .944, .936, .946, .927, .919, .904 and .938 correspondingly.

Then, a reliability analysis was carried out on the pretest and posttest of the self-efficacy scale of MSLQ, which comprises eight items. Cronbach's alpha showed a reliability (α) of .893 and .919 correspondingly, which is regarded as acceptable.

Lastly, a reliability analysis was carried out on the pretest and posttest of metacognitive ability (elaboration, organization and metacognitive self-regulation) scale of MSLQ, which comprises twenty-eight items. Cronbach's alpha shows that the reliability was acceptable (α = .847 and .915 respectively). A summary of the reliability analyses on the above instruments is shown in table 1.

For each of the reliability tests, the sample size was 54.

Table 1

A summary of the reliability analyses on the instruments in this study

Scale	Subscale	No. of items	Cronbach's Alpha	*N*
MOLE-S	Metacognitive demand	5	.944	54
	Student-student discourse	5	.936	54
	Student-teacher discourse	5	.946	54
	Student voice	5	.927	54
	Distributed control	5	.919	54
	Teacher encouragement and support	5	.904	54
	Emotional support	5	.938	54
MSLQ – pretest	Self-efficacy	8	.893	54
	Metacognition	20	.847	54
MSLQ – posttest	Self-efficacy	8	.919	54
	Metacognition	20	.915	54

4.2 Results of independent sample *t*-test on MOLE-S showing the classroom environment of the intervention and control groups

Among the seven sections of the MOLE-S questionnaire, statistically significant difference was obtained between students from intervention group and control group for the section of metacognitive demand with t (52) = 2.07, $p < .05$ (two-tailed). On average, students from the intervention group (M = 5.02, SD = 1.21) regarded the lesson had a higher metacognitive demand than students from the control group (M = 4.25, SD = 1.51). The differences in students' views on the metacognitive demand of the lessons will be discussed in next chapter. However, there were no significant differences between students from the intervention group and control group in terms of the other variables, namely student-student discourse, student-teacher discourse, student voice, distributed control, teacher encouragement and support and emotional support. The descriptive statistics of the above indicators are listed in table 2.

Overall speaking, the intervention could provide students with a classroom environment with higher metacognitive demand than conventional teaching based on the students' feedback.

Table 2

The descriptive statistics of different indicators of the MOLE-S

	Intervention (*N*=31)		Control (*N*=23)			
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Metacognitive demand of the lesson	5.02	1.21	4.25	1.51	2.07	.043
Student-student discourse	4.83	1.10	4.52	1.33	.899	.374
Student-teacher discourse	4.77	1.26	4.29	1.25	1.39	.171
Student voice	5.02	1.18	5.02	1.21	.009	.993
Distributed control	4.78	1.16	4.51	1.14	.822	.415
Teacher encouragement and support	5.09	.883	4.75	1.16	1.17	.248
Emotional support	5.30	.899	5.07	1.37	.704	.486

4.3 Research Question 1

What is the effect of metacognitive-rich SSI on students' metacognitive regulation?

4.3.1 Results of 2x2 mixed ANOVA showing metacognitive regulation of students from the two groups

Before conducting the 2x2 ANOVA analysis, an independent samples *t*-test was conducted on pretest score of metacognitive regulation by students from the two groups. There was no statistically significant difference in metacognitive regulation at pretest between students from the intervention group and control group ($p > .05$).

Then, a 2x2 mixed ANOVA was conducted to compare the metacognitive regulation of students (within-subject) from intervention group and control group (between subject) using their responses to the MSLQ questionnaires. The result revealed that there was a significant interaction effect between metacognitive regulation of students and student groups with F (1, 52) = 6.60, $p < .05$, suggesting that the metacognitive regulation of students was different for the intervention group and control group. The main effect of metacognitive regulation at the pretest and posttest was significant with F (1, 52) = 12.92, $p < .005$. There were significant differences in metacognitive regulation at pretest and posttest. Pairwise comparisons of metacognitive regulation with Bonferroni adjustment were conducted to compare the main effect of metacognitive regulation at the pretest and posttest. The mean metacognitive regulation of students from the intervention group was significantly higher at the posttest (Intervention: $M = 4.95$, $SD = .640$, Control: $M = 4.63$ $SD = .606$) than the mean metacognitive regulation at the pretest (Intervention: $M = 4.42$, $SD = .565$, Control: $M = 4.55$, $SD = .639$).

The results suggest that, on average, students from the intervention group had a higher metacognitive regulation at the posttest ($p < .001$). The effect size was medium with 11.3% ($\eta^2 = .113$) of the change in metacognitive regulation being accounted for by the student group. The change in metacognitive regulation of students from pretest to posttest is shown in figure 6. The descriptive statistics and ANOVA summary of metacognitive regulation by student group is shown in table 3.

4.3.2 Results of independent samples *t*-test on gain in score on metacognitive regulation by students from the two groups

There was significant difference between students from the intervention group and control group in terms of the gain in score on metacognitive regulation with a medium effect [t (52) = 2.65, $p < .05$, $d = .72$]. On average, students from the intervention group ($M = .523$, $SD = .667$) exhibited a higher gain in score on metacognitive regulation than students from control group ($M = .087$, $SD = .539$), and the difference was statistically significant. The descriptive statistics and the effect size of the above *t*-test are listed in table 7.

In conclusion, findings of the above 2x2 mixed ANOVA could be supported by the independent samples *t*-test. Students in the intervention group outperformed students in the control group, showing significantly higher metacognitive regulation with a medium to large effect.

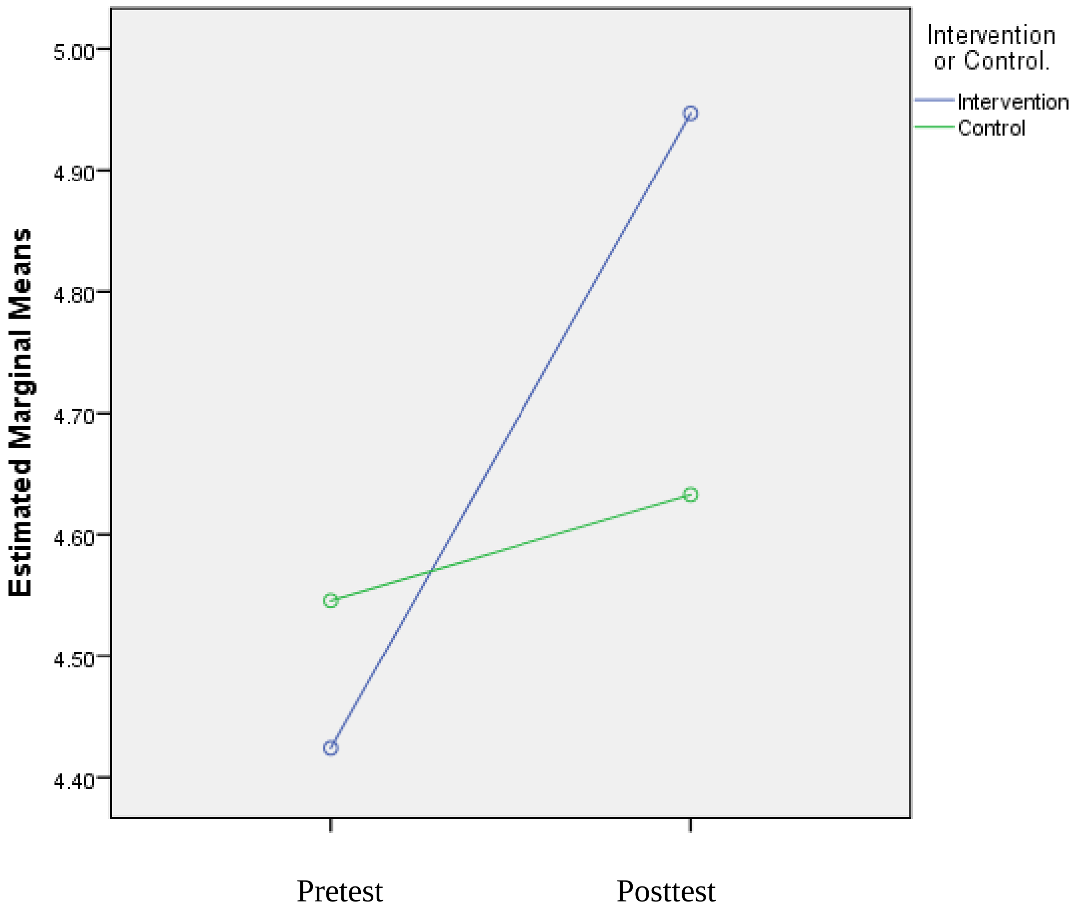

Figure 6

A graph showing the change in students' metacognitive regulation before and after the intervention by student groups

Table 3

The descriptive statistics and ANOVA summary of metacognitive regulation by student groups

Score	*M*	*SD*	*N*	η^2
Intervention				
Pretest	4.42	.565	31	
Posttest	4.95	.640	23	
Control				.113
Pretest	4.55	.639	31	
Posttest	4.63	.606	23	

Source	*SS*	*Df*	*MS*	*p*	*F*
Score	2.45	1	2.45	.001	12.92 **
Student	1.25	1	1.25	.013	6.60*
Group					
Error	9.88	52	.19		

**$p < .005$

* $p < .05$

4.4 Research Question 2

What is the effect of metacognitive-rich SSI on students' self-efficacy?

4.4.1 Results of 2x2 mixed ANOVA showing self-efficacy of students from the two groups

Before conducting the 2x2 ANOVA analysis, an independent samples *t*-test was conducted on pretest score of self-efficacy by students from the two groups. There was no statistically significant difference in self-efficacy at pretest between students from the intervention group and control group ($p > .05$).

Then, a 2x2 mixed ANOVA was conducted to compare the self-efficacy of students (within-subject) from the intervention group and control group (between subjects) using their responses to the MSLQ questionnaires. The result revealed a significant interaction effect in self-efficacy of students and student groups [F (1, 52) = 8.48, $p < .005$], suggesting that the self-efficacy of students was different for the intervention group and control groups. There were statistically significant differences in self-efficacy at the pretest and posttest [F (1, 52) = 22.34, $p < .005$]. Pairwise comparisons of self-efficacy with Bonferroni adjustment were conducted to compare the main effect of self-efficacy (pretest and posttest). The mean self-efficacy of student of the intervention group was significantly higher at the posttest (Intervention: M = 5.11, SD = .700, Control: M = 4.59, SD =.684) than the mean self-efficacy at the pretest (Intervention: M = 4.47, SD = .553, Control: M = 4.44, SD = .682).

The results suggest that, on average, students from the intervention group showed a higher self-efficacy at the posttest than the pretest ($p < .005$). The effect size is large with 14% ($\eta^2 = .14$) of the change in the metacognitive regulation can be accounted for by the student group. The change in self-efficacy of students from pretest to posttest is shown in figure 7. The descriptive statistics and ANOVA summary of self-efficacy by student group is shown in table 4.

4.4.2 Results of independent samples *t*-test on gain in score on self-efficacy by students from the two groups

There was a statistically significant difference between students from the intervention group and control groups in terms of the gain in score on self-efficacy with a large effect [t (52) = 2.98, $p < .005$, $d = .81$]. On average, students from the intervention group ($M = .644$, $SD = .655$) acquired a significantly higher gain in score on self-efficacy than students from the control group ($M = .153$, $SD = .553$). The descriptive statistics and the effect size of the above t-test are listed in table 7.

In conclusion, findings of the above 2x2 mixed ANOVA could be supported by the independent samples *t*-test. Students in the intervention group outperformed students in the control group, showing significantly higher self-efficacy with a large effect.

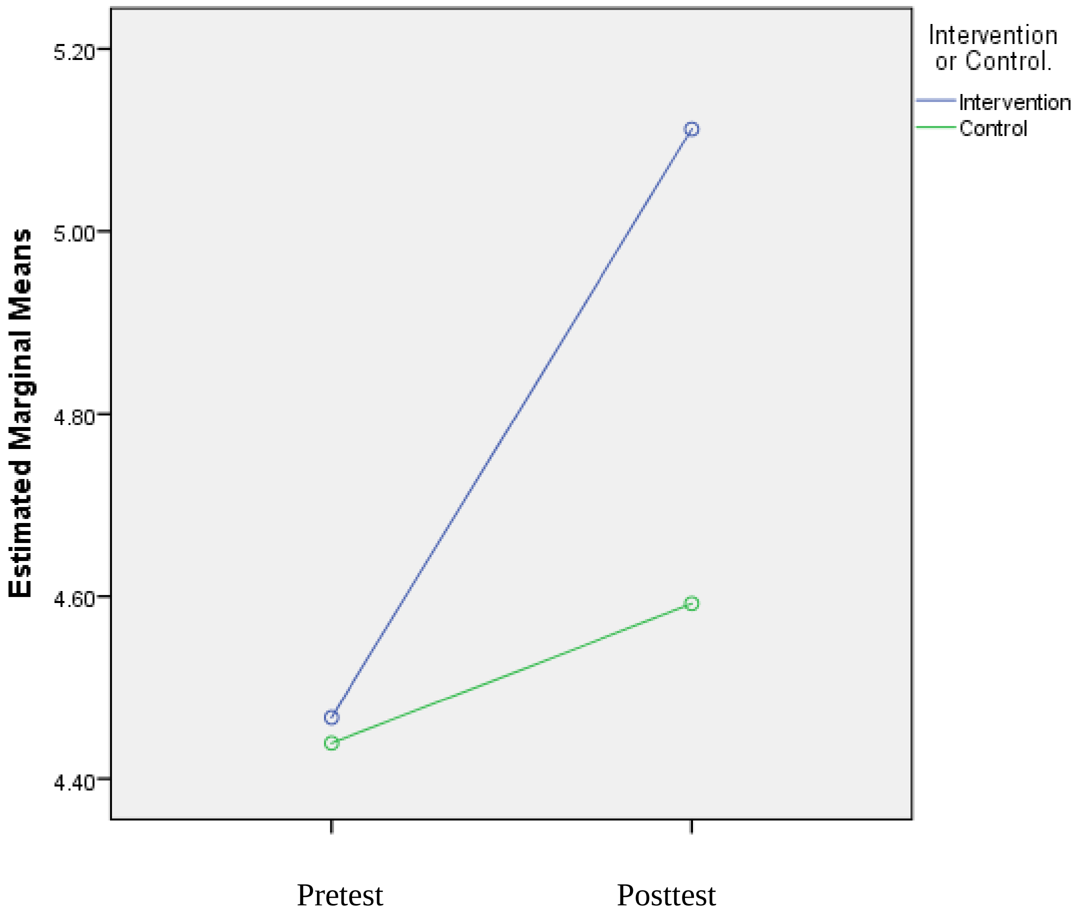

Figure 7

A graph showing the change in students' self-efficacy before and after the intervention by student groups

Table 4

The descriptive statistics and ANOVA summary of self-efficacy by student groups

Score	*M*	*SD*	*N*	η^2
Intervention				
Pretest	4.47	.553	31	
Posttest	5.11	.700	23	
Control				.14
Pretest	4.44	.682	41	
Posttest	4.59	.684	23	

Source	*SS*	*Df*	*MS*	*p*	*F*
Score	4.21	1	4.21	.000	22.34**
Student Group	1.60	1	1.60	.005	8.48**
Error	9.80	52	.188		

**$p < .005$

* $p < .05$

4.5 Research Question 3

What is the effect of metacognitive-rich SSI on students' conceptual understanding?

4.5.1 Results of 2x2 mixed ANOVA showing the conceptual understanding by students from the two groups

Before conducting the 2x2 ANOVA analysis, an independent samples t-test was conducted on pretest score of conceptual understanding by students from the two groups. There was no statistically significant difference in conceptual understanding at pretest between students from the intervention group and control group ($p > .05$).

Then, a 2x2 mixed ANOVA was conducted to compare the conceptual understanding of students (within-subject) by using their scores of the pretest and posttest from the intervention group and control group (between subjects). The result revealed that there was significant interaction effect between conceptual understanding of students and student groups with F (1, 52) = 7.23, $p < .05$, suggesting that the conceptual understanding of students was different for the intervention group and control group. The effect size is medium with 12% ($\eta^2 = .12$) of the change in the metacognitive regulation can be accounted for by the student group. However, the main effect of the student groups and mean conceptual understanding were equal at the pretest and posttest with and F (1, 52) = 1.93, $p > .05$. Overall speaking, there were no significant differences in conceptual understanding at the pretest and posttest for both the intervention and control groups. The change in conceptual understanding of students from pretest to posttest is shown in figure 8. The descriptive statistics and ANOVA summary of conceptual understanding by student group is shown in table 5.

4.5.2 Results of independent samples t-test on gain in score on conceptual understanding by students from the two groups

Different from the ANOVA finding, there was a statistically significant difference between students from the intervention group and control group in terms of the gain in score on conceptual understanding with a medium effect [t (52) = 2.63, $p < .05$, $d = .73$]. On average, students from the intervention group (M = 5.56, SD = 9.30) exhibited a significant higher gain in score on conceptual understanding than students from the control group (M = -1.768, SD =10.67). The descriptive statistics and the effect size are listed in table 7.

In conclusion, findings from the 2x2 mixed ANOVA of conceptual understanding could not be supported by the independent sample *t*-test. This leads to further discussion in next chapter. The results of descriptive statistics of performance (metacognitive regulation, self-efficacy and conceptual understanding) by student group are summarized in table 6.

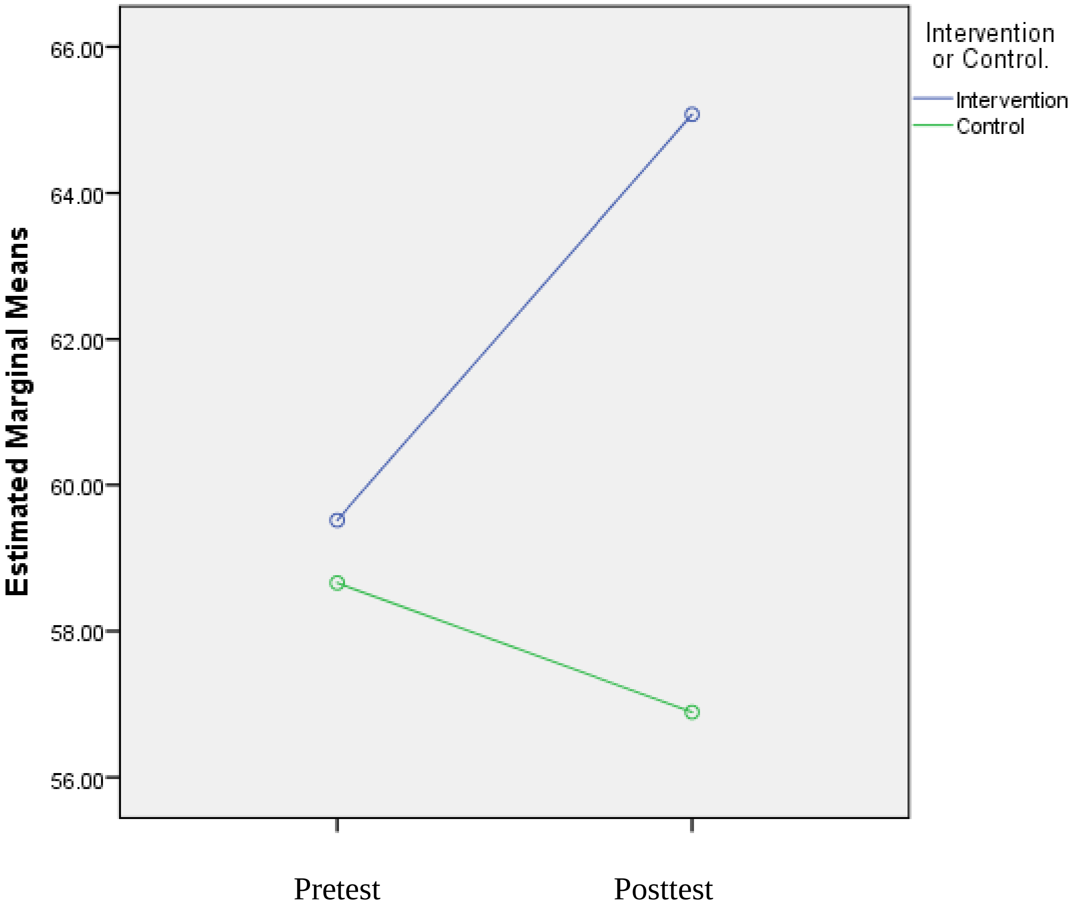

Figure 8

A graph showing the change in students' conceptual understanding before and after the intervention by student groups

Table 5

The descriptive statistics and ANOVA summary of conceptual understanding by student groups

Score	*M*	*SD*	*N*	η^2
Intervention				
Pretest	59.52	9.71	31	
Posttest	65.07	9.16	23	
Control				.12
Pretest	58.66	12.13	31	
Posttest	56.89	13.21	23	

Source	*SS*	*Df*	*MS*	*p*	*F*
Score	94.88	1	94.88	.17	1.93
Student	354.45	1	354.45	.01	7.23 *
Group					
Error	2551.12	52	49.06		

* $p < .05$

Table 6

The descriptive statistics of dependent variables (metacognitive regulation, self-efficacy and conceptual understanding) by student groups

	Dependent variables								
	Metacognitive regulation			Self-efficacy			Conceptual understanding		
Score	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
Intervention									
Pretest	4.42	.565	31	4.47	.553	31	59.52	9.71	31
Posttest	4.95	.640	23	5.11	.700	23	65.07	9.16	23
Control									
Pretest	4.54	.639	31	4.44	.682	41	58.66	12.13	31
Posttest	4.63	.606	23	4.59	.734	23	56.89	13.21	23

Table 7

A summary of the descriptive statistics and the effect size of the gain in score on all the dependent variables (metacognitive regulation, self-efficacy and conceptual understanding) by student groups

Gain in score (Posttest-Pretest)	Intervention (N=31)		Control (N=23)				Effect size
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*	Coden's *d*
Metacognitive regulation	.523	.667	.087	.539	2.65	.011	.72
Self-efficacy	.644	.655	.153	.553	2.98	.004	.81
Conceptual understanding	5.56	9.30	-1.77	10.67	2.63	.012	.73

4.6 Research Question 4

How do metacognitive regulation, self-efficacy and conceptual understanding correlate with each other in metacognitive-rich SSI?

4.6.1 Results of one-way MANOVA showing the gain in scores on performance (metacognitive regulation, self-efficacy and conceptual understanding) by the two student groups

A one-way MANOVA was conducted with the two student groups as independent variables, and with the gain in scores in metacognitive regulation, self-efficacy and conceptual understanding as dependent variables. The independent variables are intervention group and control group. There was a statistically significant difference in multivariate test of the gain in score on metacognitive regulation, self-efficacy and conceptual understanding by the two student groups in favour of the intervention group [F (3, 50) = 4.339, p < .01; Wilk's Λ = .793] with a large effect ($\eta 2$ = .207). Table 8 shows the MANOVA summary of gain in scores on performance

Table 8

MANOVA summary of gain in scores on performance by student groups

Dependent variables (Gain in score)	*df*	*df* error	*F*	*M*	95% Confidence Interval Upper bound	95% Confidence Interval Lower bound	Partial Eta Squared ($\eta 2$)	Multivariate test F	Wilk's Λ
Metacognitive regulation (Intervention)	1	52	6.594*	.523	.300	.745			
Metacognitive regulation (Control)				.087	-1.71	.345			
Self-efficacy (Intervention)	1	52	8.447**	.644	.423	.866			
Self-efficacy (Control)				.153	-1.03	.410	2.07	4.339**	.793
Conceptual understanding (Intervention)	1	52	7.225*	5.56	1.99	9.129			
Conceptual understanding (Control)				-1.77	-5.91	2.377			

**p < .005

*p < .05

4.6.2 Results of Pearson correlation among the 'pretest score' for metacognitive regulation, self-efficacy and conceptual understanding

A Pearson correlation was computed to assess the relationship between the pretest score on metacognitive regulation, self-efficacy and conceptual understanding. There was a relatively strong positive correlation between the pretest score on self-efficacy and metacognitive regulation (r = .468, n = 54, p <.005). Table 9 below shows the Pearson correlation matrix among the pretest scores for the dependent variables.

Table 9

Pearson correlation matrix among the pretest scores for the dependent variables

	Pretest score of Metacognitive regulation	Pretest score of Self-efficacy	Pretest score of Conceptual understanding
Pretest score of Metacognitive regulation		.468**	.040
Pretest score of Self-efficacy	.468**		.161
Pretest score of Conceptual understanding	.040	.161	

**p < .01

4.6.3 Results of Pearson correlation among the 'posttest score' for metacognitive regulation, self-efficacy and conceptual understanding

Again, Pearson correlation was computed to assess the relationship between the posttest score on metacognitive regulation, self-efficacy and conceptual understanding. There were positive correlations: (1) between the posttest score on metacognition and the posttest score on self-efficacy (r = .812, n = 54, p < .005); (2) between the posttest score on metacognitive regulation and the posttest score on conceptual understanding (r = .345, n = 54, p < .05); and (3) between the posttest score on self-efficacy and the posttest score on conceptual understanding (r = .376, n = 54, p < .005). It is noteworthy that the posttest score on metacognitive regulation and self-efficacy were strongly positively correlated. Table 10 below shows the Pearson correlation matrix among the posttest scores of the dependent variables.

Table 10

Pearson correlation matrix among the posttest scores of the dependent variables

	Posttest score of Metacognitive regulation	Posttest score of Self-efficacy	Posttest score of Conceptual understanding
Posttest score of Metacognitive regulation		.812**	.345*
Posttest score of Self-efficacy	.812**		.376**
Posttest score of Conceptual understanding	.345*	.376**	

**p < .01

*p < .05

4.6.4 Results of Pearson correlation between gain in scores for metacognitive regulation, self-efficacy and conceptual understanding

Lastly, Pearson correlation was computed to assess the relationship between the gain in scores for metacognitive regulation, self-efficacy and conceptual understanding. There were positive correlations: (1) between the gain in score on metacognitive regulation and gain in score on self-efficacy (r = .567, n = 54, p < .001); (2) between the gain in score on metacognitive regulation and gain in score on conceptual understanding (r = .273, n = 54, p < .05); and (3) between the gain in score on self-efficacy and gain in score on conceptual understanding (r = .394, n = 54, p < .005). It was notable that positive correlation between the gain in score on metacognitive regulation and gain in score on self-efficacy were the strongest of all. Table 11 below shows the Pearson correlation matrix among the gain in score on the dependent variables.

Table 11

Pearson correlation matrix among the gain in score on dependent variables

	Gain in Metacognitive regulation	Gain in Self-efficacy	Gain in Conceptual understanding
Gain in Metacognitive regulation		.567**	.273*
Gain in Self-efficacy	.567**		.394**
Gain in Conceptual understanding	.273*	.394**	

**p < .01

*p < .05

4.7 Qualitative analysis

All the 31 students in the intervention group showed up and agreed to participate in the interview. They were clearly informed that they were free to decline to participate without any adverse consequences. The researcher first explained to the students during the individual interview the meaning of “socio-scientific issues” “metacognitive task” and “self-confidence”. He then introduced four aspects of learning to the interviewees including: (1) impression about the metacognitive-rich SSI; (2) regulation of learning strategies in completing different tasks; (3) evaluation and reflection upon the completion of tasks; and (4) whether intervention increase or decrease self-confidence. Students were encouraged by the researcher to describe in detail how these aspects have changed or remained unchanged throughout the intervention. Their responses were recorded using the internal microphone program of Apple iPhone 6s plus. Their responses were transcribed carefully. The transcription was analyzed based on the thematic analysis approach (Bogdan & Biklen, 1998; Braun & Clark, 2006). The interview responses were analyzed with the generation of emergent categories through a coding practice. The researcher paraphrased the interviews of different students to generate the codes (Corbin & Strauss, 1990). Using the thematic analysis method, the most frequently occurred items about metacognition regulation and factors of self-efficacy were coded and summarized to identify overarching, consistent and prominent themes. The interview data were carefully analyzed to deduce possible benefits of using a metacognitive-rich SSI approach on students’ metacognition and self-efficacy.

According to the statistical analysis, metacognitive regulation, self-efficacy and conceptual understanding showed positive correlations with each other. These data suggest that the three variables were interrelated. A gain in the metacognitive regulation could be a result of a gain in self-efficacy, or vice versa, or due to another unknown variable acting on these known variables at the same time. Also, metacognitive regulation and self-efficacy have a higher positive correlation compared with the others. Attempting to explain the above interrelations, students' responses were analyzed thoroughly thematically to identify any signs of changes in metacognitive regulation and self-efficacy throughout the study period. To investigate into the interaction between the metacognitive regulation and self-efficacy among students of the intervention group, two rounds of thematic analyses were deployed to evaluate how students' metacognitive regulation and self-efficacy were changed throughout the intervention with different themes about metacognitive regulation and self-efficacy.

In the first round of thematic analysis, the researcher looked for responses from students with respect to four themes in relation to the learning environment of the intervention process: (1) benefits of the ME-rich SSI, (2) learning strategies bought about by the ME-rich SSI, (3) learning strategies demonstrated by students in the ME-rich SSI, and (4) motivational effect brought about by the ME-rich SSI. Under each theme, various sub-themes were identified as shown in table 11. The subthemes were aligned with the terms broadly accepted by other researchers in the field as and where appropriate.

In the second round of thematic analysis, the researcher looked for different metacognitive regulation indicators which showed the process of metacognitive regulation including: (1) planning, (2) monitoring and (3) evaluation, and different self-efficacy indicators reflecting the four sources of self-efficacy – (1) mastery experience, (2) vicarious experience, (3) social persuasion and (4) emotional arousal. The coding process was similar to the first thematic analysis.

4.8 First thematic analysis on interview transcripts

Views of students towards the implementation of the socio-scientific issues and metacognitive activities were collected. The responses were categorized into 4 main themes – (1) Benefits of the ME-rich SSI, (2) learning strategies bought about by the ME-rich SSI, (3) learning strategies demonstrated by students in the ME-rich SSI and (4) motivational effect bought about by the ME-rich SSI. A summary table showing the detailed codes could be found in table 12**.** The following sample coded transcripts show how the analysis was done:

Sample coded transcript of student 1 in the first thematic analysis

'The teaching mode is different compared to the past. I find the things by myself. [finding information] I am more interested. It did not follow the book to teach. It had other extra information and was more comprehensive. [better delivery] The metacognitive task is useful. I was clearer to what I are doing. Doing project is a good way for me to find the information which is not covered in the book by myself. I have deeper understanding to ecology. [deeper understanding] In the past, no project, just follow book, just exercise. It is closer to the real society. Applied ecology should be applied to life events, using issue to relate ecology and biodiversity is a very authentic example. [authentic example] Unlike nitrogen cycle which is very theoretical, socio-scientific issue is clearer. In the past, I just revise the book, read the book. I try to gather more information on the internet. The book information is not all rounded, I need to get more information to learn it better. Although I didn't revise enough for ecology, I have certain knowledge. The thinking skills can be applied to other topics to make the progress smooth. The method is better than the past because it can increase my interest [more interested] towards biology and I will go to find more information automatically and thinking in deeper level. [promote thinking]'

Analysis of student 1's view

Sub-themes (codes) [finding information], [better delivery], [deeper understanding], [authentic example], [more interested] and [promote thinking] were collected from student 1's transcript.

Table 12
Themes, sub-themes (codes) and sample coding processes in the first thematic analysis

Themes	Sub-themes (code)	Sample coding processes
Benefits of ME-rich SSI	'promote thinking' 'authentic example' 'better delivery' 'arouse awareness' 'fit NOS' 'make judgement' 'better classroom environment' 'constructivist way' 'richer content'	Student 1: 'Applied ecology should be applied to life events, using issue to relate ecology and biodiversity is a very authentic example' is coded into 'authentic example' Student 5: 'I can bravely express my stance, and I can develop better within my stance' is coded into 'make judgement' Student 10: 'Notes has richer content than book' is coded into 'richer content'
Learning strategies bought about by the ME-rich SSI	'Provide direction' 'better understanding' 'metacognitive knowledge' 'link prior knowledge' 'help consolidate' 'different learning strategies'	Student 2: 'The thinking tool requiring me to distinguishing the impacts into different aspects about Tai Po Industrial Plant, this helps me learn with prior knowledge' is coded into ''link prior knowledge' Student 11: 'The metacognition checking is useful to consolidate my knowledge because I think immediately about the knowledge when I see the question' is coded into 'help consolidation'
Learning strategies demonstrated by students in the ME-rich SSI	'Finding information' 'regulate my learning' 'asking question' 'fieldtrip' 'map reading' 'check understanding' 'read again' 'want formative assessment' 'connect prior knowledge' 'change way of studying' 'discussion'	Student 16: 'I think the task can motivate me to find information on the internet' is coded into 'finding information' Student 18: 'I evaluated and reflected. Through the project, it is a very good reflection' is coded into 'regulate my learning' Student 22: 'I ask myself again if I am clear about that' is coded into 'asking question'
Motivational effect bought about by the ME-rich SSI.	'higher self-confidence' 'more interest' 'deeper/better understanding' (reduced anxiety) 'better answering/generalization skills' (reduced anxiety) 'easier to learn and understand' (reduced anxiety) 'higher/clear aim to study better' 'higher efficiency' 'more motivation' 'sense of participation'	Student 24: 'I know the Ting Kok plus. It is easier to arouse interest and is better than using the book directly' is coded into 'more interested' Student 28: 'The thinking tools like the guiding questions and skills can help us answer better' is coded into better answering/generalization skills Student 30: 'My self-confidence increases because this approach can help me study science and biology' is coded into 'higher self-confidence'

4.8.1 Students' perceptions of the benefits of the ME-rich SSI

For theme (1) 'Benefits of the ME-rich SSI', the responses were further categorized into 9 sub-themes which is shown in figure 9. It was shown that students in the intervention group though that using socio-scientific issues to teach biology can (i) promote thinking from multiple perspectives (12 times), (ii) link authentic examples to the curriculum (12 times), (iii) deliver content more effectively (11 times), (iv) provide a better classroom environment (8 times), (v) provide richer content to students (7 times), (vi) fit with the nature of science (6 times), (vii) arouse environmental awareness (5 times), (viii) allow students to make judgement (4 times) and (ix) build knowledge in a constructivist way (3 times).

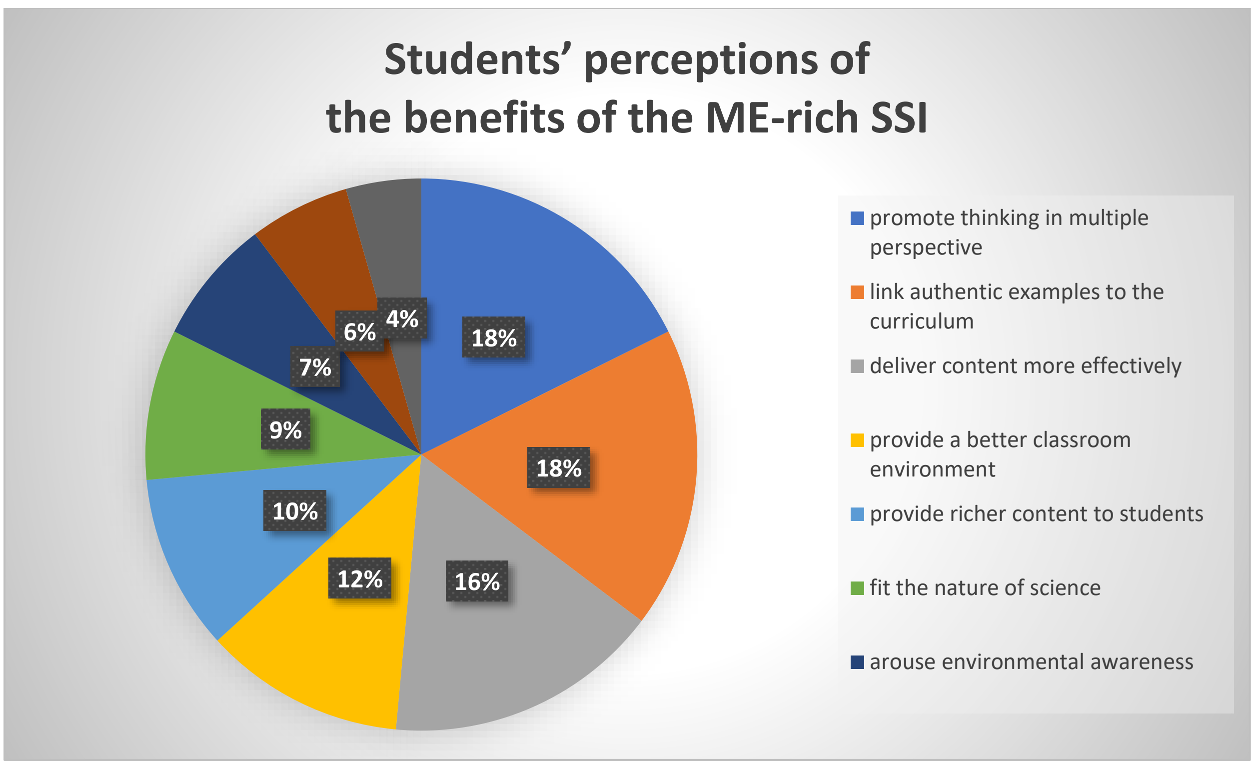

Figure 9

A pie chart showing students' perceptions of the benefits of the ME-rich SSI

4.8.2 Students' views on the learning strategies brought about by the ME-rich SSI

For theme (2) 'The learning strategies bought about by the ME-rich SSI, the responses were further categorized into 6 sub-themes which is shown in figure 10. It was shown that students in the intervention group thought ME-rich SSI can (i) help link new knowledge to prior knowledge in biology (9 times), (ii) provide directions about studying (8 times), (iii) develop better understanding (5 times), (iv) deliver metacognitive knowledge (5 times), (v) help consolidate knowledge (3 times) and (vi) provide different learning strategies (3 times).

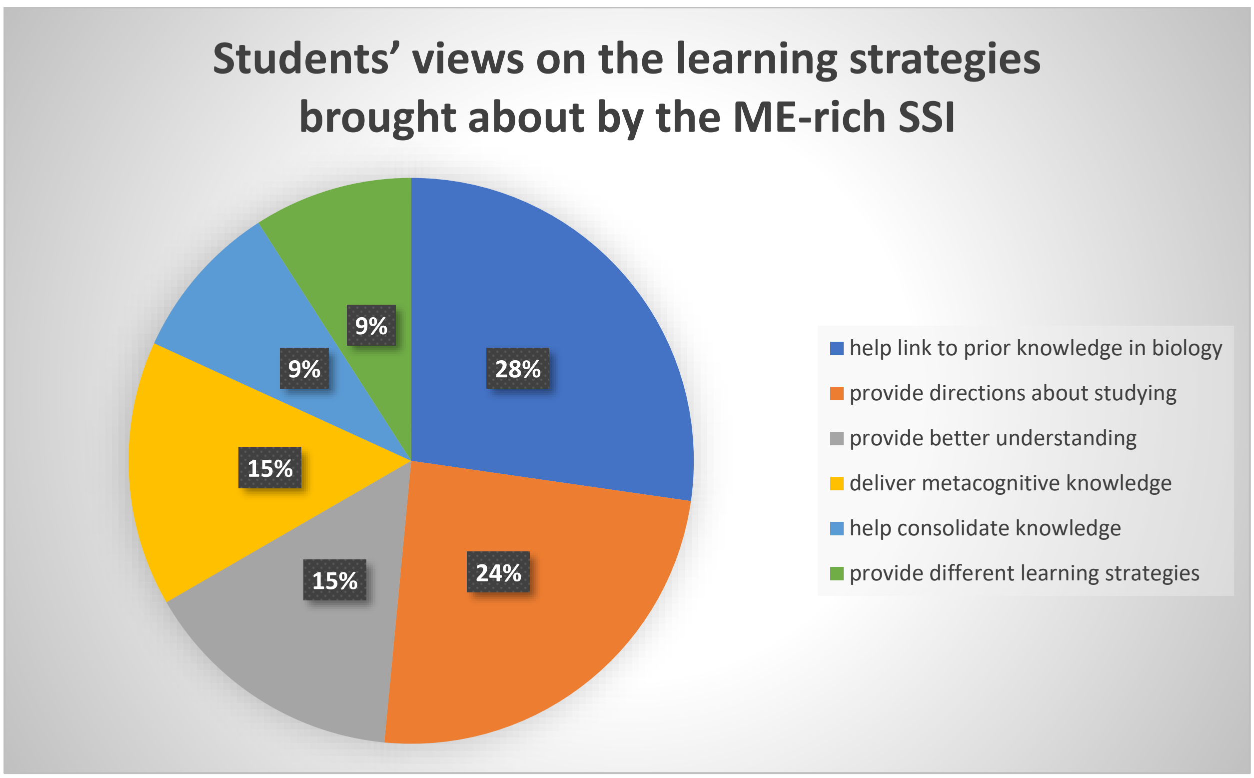

Figure 10

A pie chart showing students' views on the learning strategies brought about by the ME-rich SSI

4.8.3 Learning strategies demonstrated by students in the ME-rich SSI

For theme (3) 'Learning strategies demonstrated by students in the ME-rich SSI', there were mainly 10 learning strategies reflected by the students which is shown in figure 11. These are namely, (i) finding information from the Internet (15 times), (ii) asking questions (13 times), (iii) regulating my learning (11 times), (iv) checking my own understanding (7 times), (v) suggesting fieldtrips to be conducted in future (7 times), (vi) discussion (7 times), (vii) reading the course materials again (6 times), (viii) using a map to learn (3 times), (ix) connecting to prior knowledge (3 times) and (x) formative assessment (1 time). The outcome of that test shows students in the intervention group perceived that the lesson had a significantly higher metacognitive demand than that perceived by the control group.

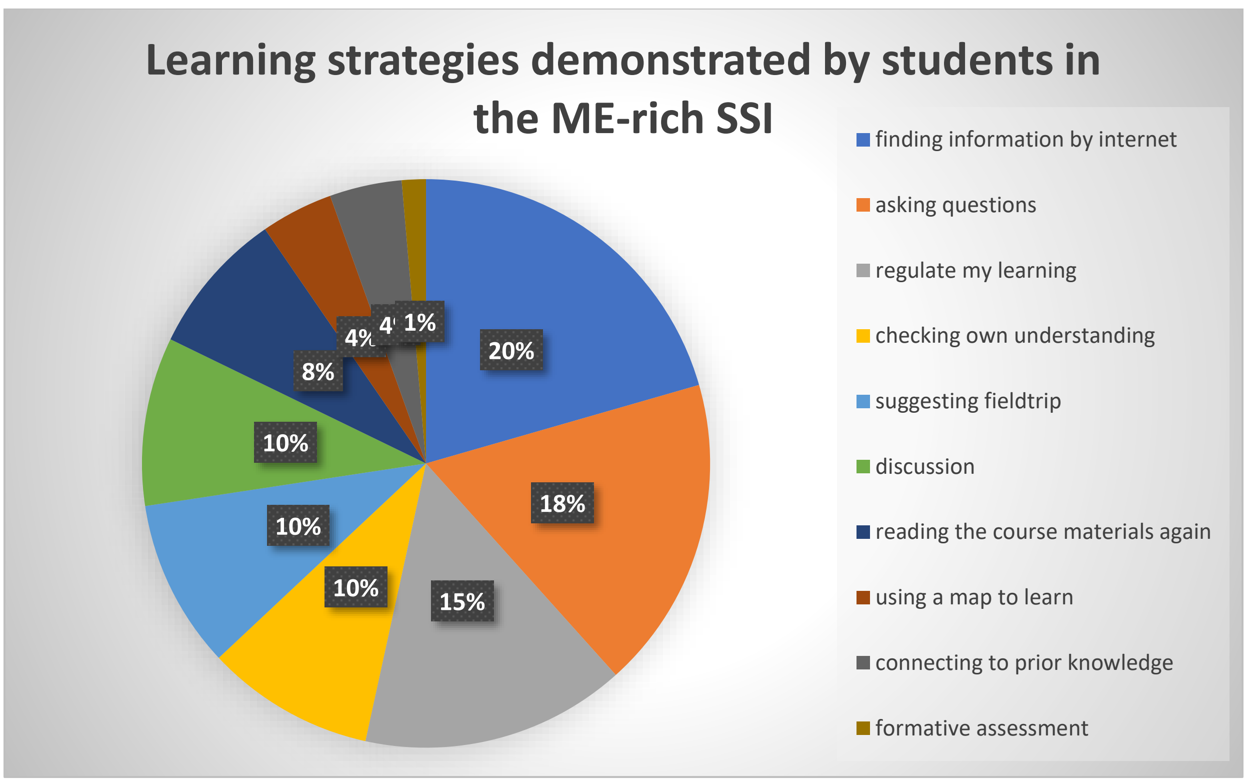

Figure 11

A pie chart showing the learning strategies demonstrated by students in the ME-rich SSI

4.8.4 Motivational effects brought about by the ME-rich SSI

For theme (4) 'Motivational effect brought about by the ME-rich SSI', there were 9 main motivational effects revealed by the interviewees which is shown in figure 12. These are namely. (i) higher self-confidence (22 times), (ii) deeper and better understanding (10 times), (iii) more interested (8 times), (iv) easier to learn and understand (8 times), (v) higher efficiency (6 times), (vi) better answering/generalization skills (5 times), (vii) higher/clearer aim to study better (2 times), (viii) more motivation (1 time) and (ix) higher sense of participation (1 time)

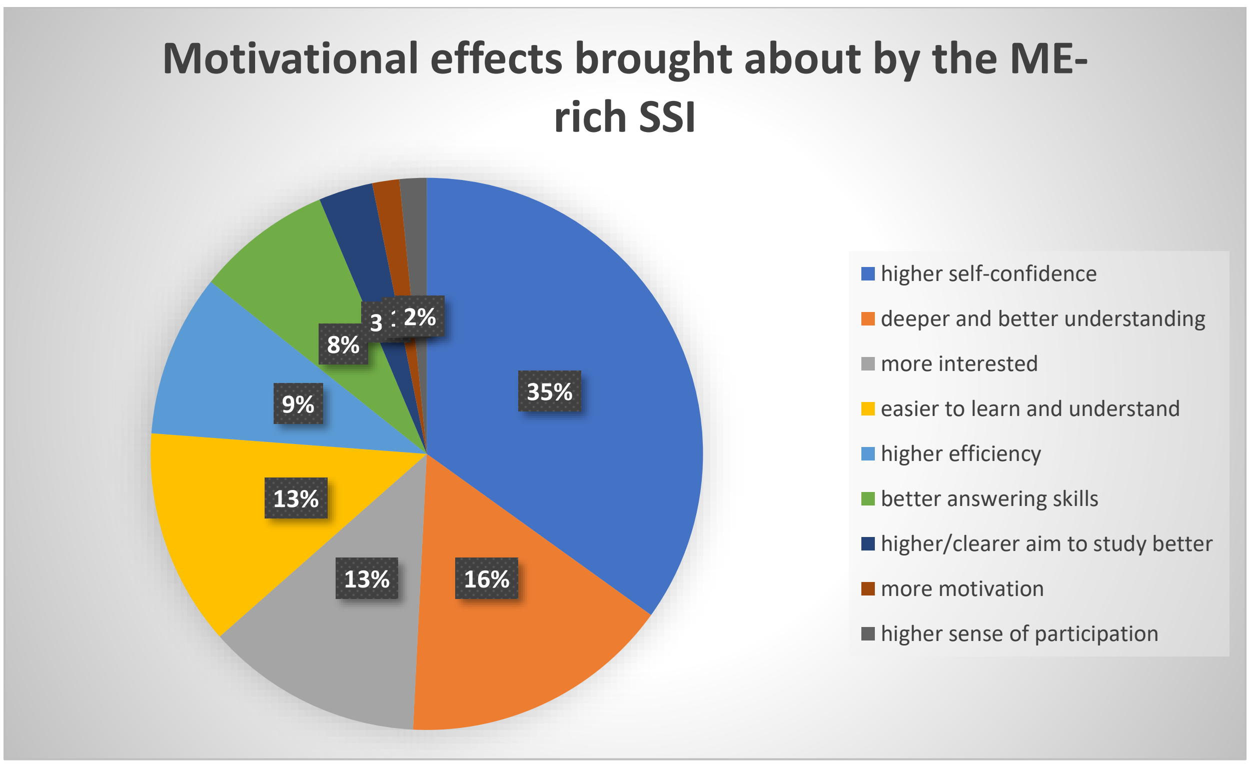

Figure 12

A pie chart showing motivational effects brought about by the ME-rich SSI

4.9 Second thematic analysis on interview transcripts

To investigate into the interaction between the metacognitive abilities and self-efficacy among students of the intervention group, a second thematic analysis was conducted to evaluate how students' different processes of metacognitive regulation, (planning, monitoring and evaluation) and factors or sources of self-efficacy (mastery experience, vicarious experience, social persuasion and emotional arousal) were demonstrated throughout the intervention. The following sample coded transcripts show how the analysis was done:

Sample 1: Coded transcripts of student 10

'Notes has richer content than book. I need to fill in blanks which requires me to understand. Before learning this topic, if I am in between a difficulty, I can ask classmates and do more information gathering. [Metacognitive indicator – planning] *The thinking skills help me think about solutions. I apply this in Liberal Studies. I ask my classmates about things I don't understand.* [Metacognitive indicator – monitoring] *I didn't do this in the past. This style of teaching can be applied to other difficult topics as well.* [Metacognitive indicator – evaluation] *There were a lot of things I can't understand. I compare others work with my own work this time.* [Self-efficacy indicator – vicarious experience] *In the past, I didn't compare. I focused on marks before and now I focus on the process more. Seeing others' presentation, I think they work hard and I want to work hard too.* [Self-efficacy indicator – social persuasion] *The topic is interesting although I didn't plan to take this elective. Taking stance increase my self-confidence because in the past, test and exam counts all. Now I can check my progress in different time point.* [Self-efficacy indicator – mastery experience] *It is because in between notes, there are questions and diversified tasks to achieve this.'*

Analysis of student 10's metacognitive regulation and self-efficacy

It can be seen that the metacognitive tasks embedded in the teaching materials allowed student 10 to actively plan, monitor and evaluate his study progress and strategies. He demonstrated the importance of such metacognitive skills in the information gathering process which is essential to learning and teaching in an SSI-based classroom. For self-efficacy, this student shared different indicators of a positive self-efficacy including social persuasion, vicarious experience and mastery experience. These indicators might have collectively contributed to the higher self-efficacy of the student. He said, '*Now I can check my progress in different time point*', which is a metacognitive monitoring skill that might have developed him to develop his self-efficacy. Metacognitive regulation and self-efficacy might also have interacted with each other in the metacognitive-rich SSI setting although more evidence is needed to confirm the assertion.

Sample 2: Coded transcripts of student 16

'It is more interesting and it is not following books. There are activities like reading map and it is more interesting but I felt less secured. [Self-efficacy indicator – emotional arousal] *I find information online with geography knowledge. I can apply appropriate skills in completing the task and it was quite smooth.* [Metacognitive indicator – monitoring] *There are lot of study on internet about Ting Kok. I want to gather information first before taking a stance. I want to have self-determination. I think the task can motivate me to find information on the internet.* [Self-efficacy indicator – social persuasion] *Using book only, I may not do that because they are already printed on the book. Metacognitive activity share similarities with Liberal Studies and mind-map give me more direction. There are different stakeholders I can find their opinions on internet.* [Metacognitive indicator – planning] *Science should rely on rote memorization. My interest increased but I have reservation on performance which should depends on effort. There can be more student discussions.'*

Analysis of student 16's metacognitive regulation and self-efficacy

Student 16 showed metacognitive planning and monitoring in his learning. However, the interview could not document his metacognitive evaluation. This could be a result of his strong belief in that success in studying science relies on rote memorization and is strongly related to his own effort. He believed he could complete the task smoothly with the use of different strategies, including the metacognitive planning and monitoring skills. For self-efficacy, he didn't show a gain in self-efficacy although he mentioned that the tasks in this topic help him build up his self-efficacy through social persuasion. Facing the cognitively demanding tasks, he said *'There are activities like reading map and it is more interesting but I felt less secured*', which is regarded as an emotional arousal. As discussed in the literature review, emotional arousal is a negative indicator of self-efficacy. He further elaborated on his desire for students' discussion, which reflects a lack of vicarious experience in his learning. Overall, the combined effect of metacognitive regulation and self-efficacy have not led him to a higher self-efficacy due to other reasons hindering such development.

Sample 3: Coded transcripts of student 30

Seeing different habitats in Hong Kong is very useful. Biology should be things happening near us and is a life example. We know some news and report about environmental issue. We make use of Tai Po to learn this is closer to us and I think it is easier to understand and study. The thinking skills can help me study differently. In the past we only have articles in the books to read. Now we have more chart and boxes to fill in. We can answer them open-mindedly. The answer we fill reflects what we actually think. We have more information to read and we can learn more effectively. [Metacognitive indicator – evaluation] *My self-confidence increases because this approach can help me study science and biology. It is different from the old method. This can trigger me to think rather than rote memorization.* [Metacognitive indicator – planning] *I have a new direction to look at science knowledge. I can use this method again later in my life. Promoting thinking is very good because I can have a different answer from others from the thinking process. But none of our answers are wrong, just another perspective.* [Self-efficacy indicator – vicarious experience] *I will use this style too. I want to go to field trip to Tai Po to look at the biodiversity and ecology there. Using SSI can help. Book examples are vague and I need to study by myself.* [Metacognitive indicator – monitoring] *With issue, which is real and authentic, we can find a lot of real data and report to help us study.* [Self-efficacy indicator – social persuasion] *Taking stance will not affect us to learn, because the topic is familiar to us. We can see the* *issue with new knowledge we learnt in the topics and we can further clarify our stance. Ting Kok plus project is not a familiar issue to me, but as a citizen we can think more about the importance of environmental protection after studying the biological knowledge. After doing the project, we can master more knowledge to support or oppose to the Ting Kok plus development.* *[Self-efficacy indicator – mastery experience]*

Analysis of student 30's metacognitive regulation and self-efficacy

Student 30 was in favour to the use of ME-rich SSI. He demonstrated metacognitive planning, monitoring and evaluation in his study process. He mentioned that '*The answer we fill reflects what we actually think.'* showed that the explicit metacognitive instruction might be effective in guiding students to develop metacognitive regulation. There are interactions between metacognition and self-efficacy. Through his metacognitive planning, he actively collected different data to assist his learning through social persuasion. At the end he owned his mastery experience in Ting Kok plus project presentation. This student pointed to the importance of a better learning experience in an open-ended issue as he mentioned '*none of our answers are wrong, just another perspective.'* This showed that how ME-rich SSI could provide him with vicarious experience about the nature of SSI which can be viewed from different perspectives. Improvement to his self-efficacy and metacognitive regulation in the SSI were well-documented in this interview transcript.

Summarizing the three interview results, the metacognitive-rich SSI appear to provide guides for some of the students to follow and think metacognitively. Also, quite a number of them agreed that they learnt better by monitoring their learning process. Many of them showed complete cycle(s) of metacognitive planning, monitoring and evaluation. Students from the intervention group also showed different self-efficacy indicators in their interview, including mastery experience, vicarious experience and social persuasion. It was found that more self-efficacy indicators were found in the vignette of students who had more metacognitive indicators.

However, the analysis showed that strong intentions on traditional studying methods like rote-memorization, which lack the application of metacognitive knowledge could lead to limited development of metacognition and self-efficacy. One student showed emotional arousal, which is regarded as a negative indicator of self-efficacy. Students who failed to complete a cycle of metacognitive planning, monitoring and evaluation also showed a limited development of self-efficacy. All the interview transcripts could be found in appendix E.

Table 13
Theme, sub-themes (codes) and sample dialogs in the second thematic analysis

Theme	Sub-theme (code)	Sample coding process
Metacognitive regulation	'planning'	Student 3: 'I have difficulty in distinguishing the geographical facts about Ting Kok, Tai Mei Tuk. I am not very sure about their locations. I use google maps to check where they are'
	'monitoring'	Student 5: '. We start from the organisms we know first can help me study better. The thinking skills reminds me to evaluate the direction of study if it is correct'
	'evaluation'	Student 10: 'Metacognitive task helps me evaluate my performance to see whether knowledge was mastered or not. Also it serves the purpose of re-understanding my own way of learning if it is feasible. If can't master, should I change the study method? This helps me better understand my study methods'
Factors/sources of self-efficacy	'mastery experience'	Student 19: 'My confidence in biology increases. I have deep impression. I do not need to read again as they are in my mind'
	'vicarious experience'	Student 21: 'I am impressed by the presentation part. From the presentation from different groups, I can learn more about Ting Kok. I didn't include some of the knowledge in my presentation but other groups' presentation can supplement the missing part'
	'social persuasion'	Student 25: 'In SSI, it will not directly tell the theory, we need to find out the common points and concepts by myself'
	'emotion arousal' (negative factor of self-efficacy)	Student 16: 'There are activities like reading map and it is more interesting but I felt less secured'

4.9.1 Metacognitive regulation (planning, monitoring and evaluation)

For 'metacognitive regulation', students' response on planning, monitoring and evaluation were coded as metacognitive regulation – 'planning', 'monitoring' or 'evaluation'. In case a student could demonstrate planning, monitoring and evaluation in the interview, he would be regarded as completing a metacognitive learning cycle. It was found that out of the 31 students of the intervention group, 27, 28 and 22 could demonstrate metacognitive planning (87%), monitoring (90%) and evaluation (71%) respectively. 22 (70%) students could complete at least one metacognitive learning cycle under the intervention of ME-rich SSI as shown in figure 13.

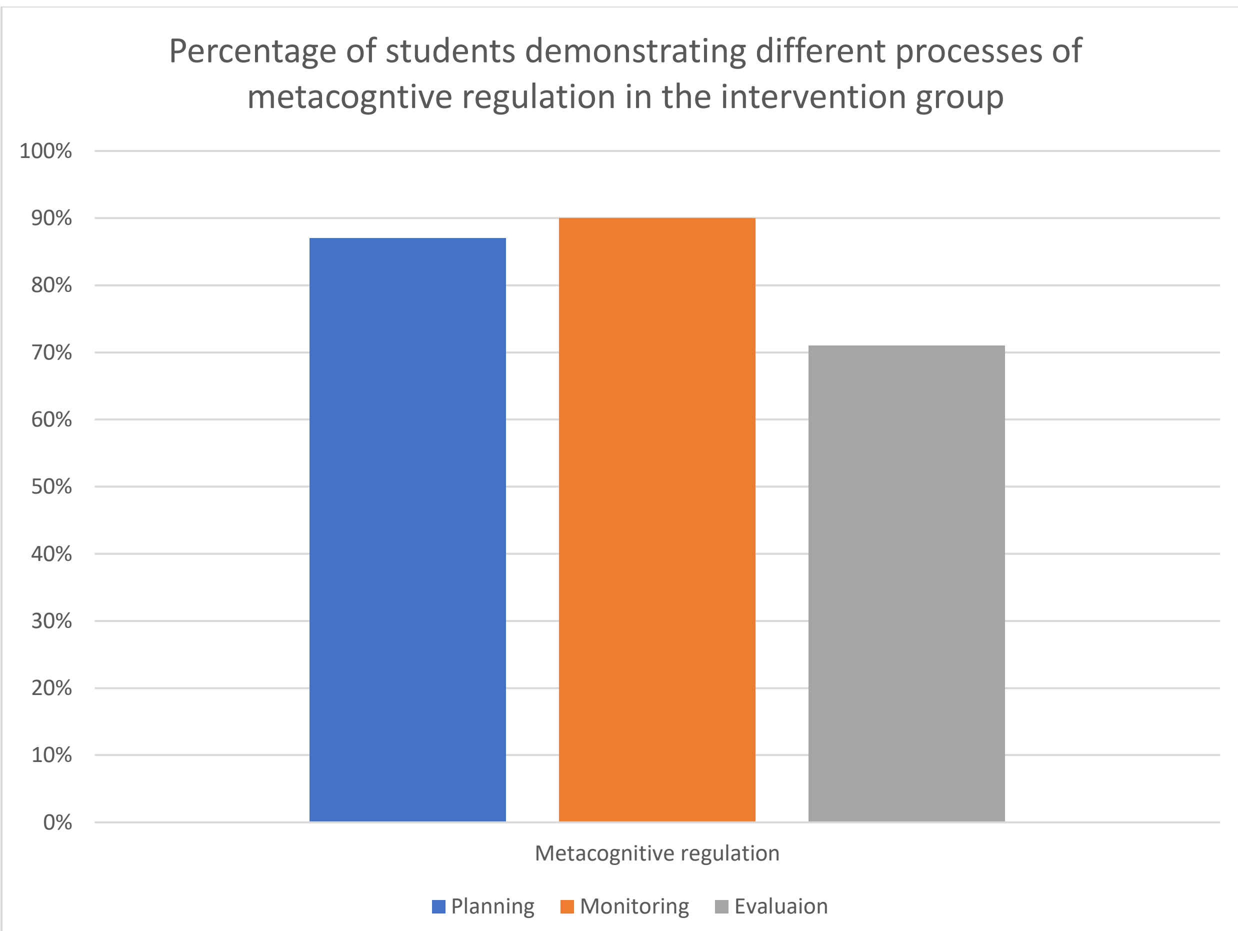

Figure 13 A bar chart showing different processes of metacognitive regulation in intervention group.

4.9.2 Factors of self-efficacy

For the 'factors/sources of self-efficacy', students' responses were coded into the four self-efficacy indicators – 'Mastery experience', 'Vicarious experience', 'Social persuasion' or 'Emotional arousal' (a negative indicator of self-efficacy)

From the result, it was found that out of the 32 students, 15, 10 and 19 reported possible gain in self-efficacy by Mastery experience (48%), vicarious experience (32%), and social persuasion (61%) correspondingly. 1 student reported emotional arousal (3%) in the interview which could lead to possible loss in self-efficacy. The results is shown in as shown in figure 14.

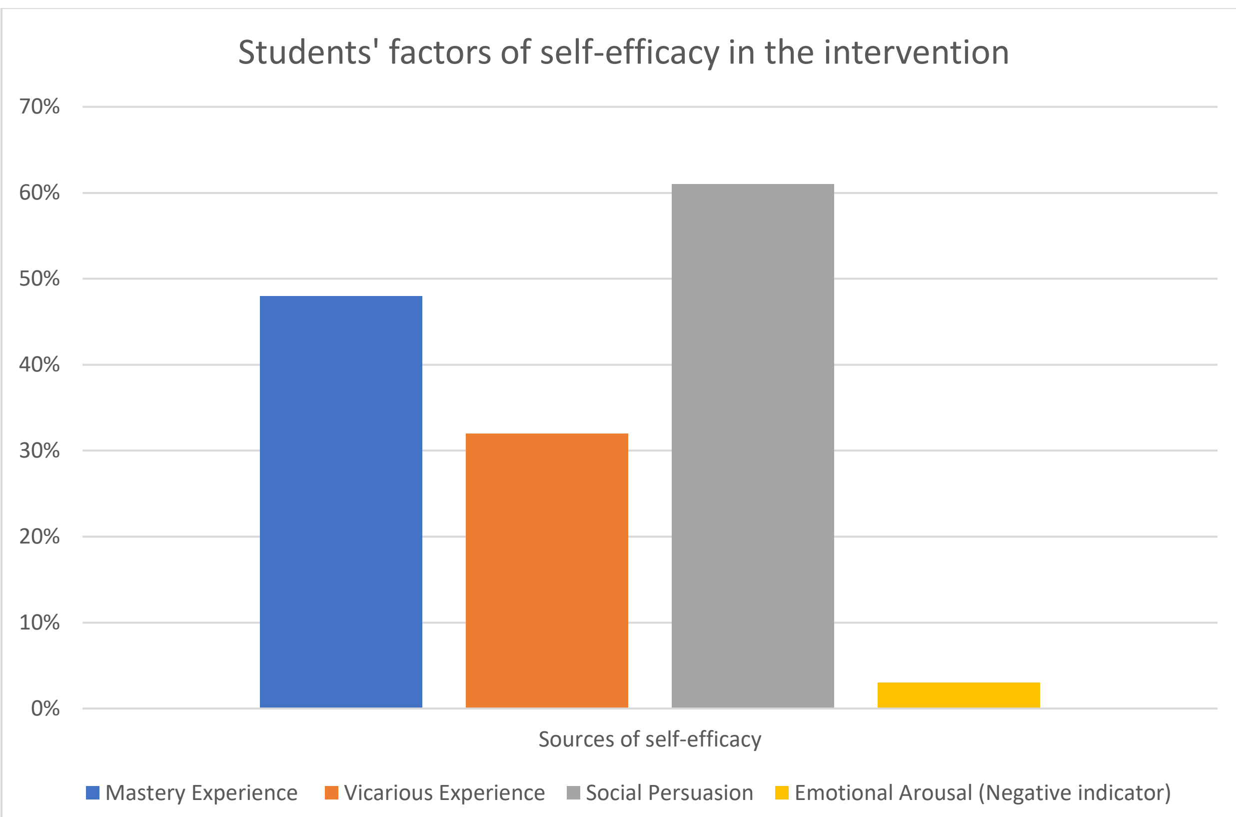

Figure 14

A bar chart showing different factors of self-efficacy in intervention group.

4.10 Summary of the findings

This quasi-experimental study used a mixed method design to introduce an intervention with the ME-rich SSI. Fifty-four twelve-grade students in a Hong Kong school were assigned to either the intervention or control group. The intervention group received ME-rich SSI intervention in teaching applied ecology with explicit metacognitive activities embedded throughout the unit. The control group received a teaching with the metacognitive activities removed and the issues were provided only at the end of the lessons. The classroom environment of both classrooms was assessed using the MOLE-S (Thomas, 2003). It was found that the intervention group perceived the lessons having higher metacognitive demand than the control group. However, other elements of a metacognition-oriented classroom environment like discourses, practices of students and teachers in a metacognition-oriented classroom were found to be similar for both groups.

To investigate into the interaction effects of student groups (between groups, independent variable) and students' performance in metacognitive regulation, self-efficacy and conceptual understanding, three 2x2 mixed design ANOVAs were conducted. The results showed that, on average, students from the intervention group had significantly higher metacognitive regulation and self-efficacy, but not conceptual understanding, at the posttest than the control group. To confirm the above investigation, the researcher also measured gain in scores on metacognitive regulation, self-efficacy and conceptual understanding based on the pretest and posttests results. The result of independent samples *t*-tests on gain in scores showed that students in the intervention group outperformed the control group in all aspects of metacognitive regulation, self-efficacy and conceptual understanding. To determine possible correlations between metacognitive regulation, self-efficacy and conceptual understanding, a one-way MANOVA and Pearson coefficient test was conducted on the gain in scores by students on the above dependent variables. The result reported that gain in scores on metacognitive regulation, self-efficacy and conceptual understanding were positively correlated. Among these correlations, the gain in scores on metacognitive regulation and gain in scores on self-efficacy were ‘moderate to high’, followed by a ‘low to moderate’ correlation between conceptual understanding and the other two dependent variables (metacognitive regulation and self-efficacy).

From students’ perception and experiences of the learning process provided by the ME-rich SSI which were collected through structured interviews, students’ perception of different learning strategies embedded in the lessons and their motivational changes were traced in the first thematic analysis. It was found that ME-rich SSI could lead to different learning outcomes in science education successfully. Students learnt and exercised different learning strategies and there were considerable motivational effects brought about by the ME-rich SSI. Lastly, students’ processes of metacognitive regulation and the factors attributing to their self-efficacy development were identified in the second round of thematic analysis. Most students reported metacognitive planning, monitoring and evaluation at least one time in the interview. It was found that metacognition and self-efficacy appeared to interact in the ME-rich SSI setting.

Discussions, conclusions and implications for practice and further research are discussed in the following section.

Chapter 5: Discussion, Implications and Conclusions

5.1 ME-rich SSI - a context to develop metacognitive regulation

From the result of the 2x2 mixed ANOVA, it was observed that the metacognitive regulation of students from the intervention group was significantly higher than the students from the control group after the intervention of a metacognitive-rich SSI. This is confirmed with the independent samples *t*-test on the gain in score on metacognitive regulation. It is believed that the improvement of metacognitive regulation in the intervention group could be a result of the design of the metacognition-oriented learning process embedded in the intervention, and the inquiry nature of the ME-rich SSI. From the result of MOLE-S, the metacognitive demand perceived by the students were higher in the intervention group compared with the control group, and the difference was statistically significant. The findings from the thematic analysis of the interview also reported that most of the students from the intervention group were able to plan, monitor and evaluate their learning strategies in the intervention process. These findings were consistent with the conceptual framework of the study that a metacognitive-rich SSI could bring positive outcome in the development of metacognitive abilities among students.

5.1.1 Explicit metacognitive knowledge instruction and the development of metacognitive regulation

Although it was believed that a high level of metacognitive regulation is a key to successful and high-quality learning, the effectiveness of learning could be limited by the design of the teaching and learning. With the setting of SSI, the metacognitive activities could be better integrated into the curriculum. Pintrich (2002) discussed the importance of the role of metacognitive knowledge in education. In terms of instruction, he underscored the need for explicit teaching of metacognitive knowledge because it is difficult for some students to develop metacognitive knowledge through implicit means. A teacher could misjudge a student as metacognitively equipped. He also mentioned that metacognitive knowledge should be embedded within the usual content-driven lessons. Such approach will have to embrace more activities, advancing students beyond contextual understanding to cognitive understanding, and finally to metacognitive understanding. These viewpoints suggested the importance of using a metacognitive-rich SSI approach to deliver science content through a content-driven instruction embedded with metacognitive strategies. This echoes the finding of the thematic analysis reported in the previous chapter that a metacognition-rich SSI approach could deliver metacognitive knowledge (15%), provide better understanding (15%), help consolidate knowledge (9%) and provide different learning strategies (9%). With the provision of a metacognitive-oriented learning environment as reflected by the outcomes of the MOLE-S, the intervention seemed to be able to develop students' metacognitive knowledge and provide opportunities for them to practice metacognitive strategies as shown by the quantitative analysis.

Students from the intervention group generally has shown a higher metacognitive regulation than those from the control group. This suggests integrating socio-scientific issue and metacognitive tasks in an ecology classroom is feasible in Hong Kong to extend the benefits of SSI beyond developing students' informal reasoning, argumentation and decision-making skills to improve students' metacognitive thinking. The above advantages may also account for the enhancement of self-efficacy as reflected from the statistical analysis. As shown by the qualitative data, using the ME-rich SSI approach is believed to promote thinking that is closely related to the development of metacognitive abilities. The above finding echoes the finding that Spellman and colleagues reported in 2016 about the importance of direct instruction of specific metacognitive strategies. They concluded that metacognitive learning could impact social-ecological problem solving in an ecology classroom.

5.1.2 Students' metacognitive regulation strategies

From the thematic analysis of students' interview, more than 70% of the students (22 out of 31) could demonstrate complete metacognitive regulation (planning, monitoring and evaluation) from the sharing of their learning experience of the ME-rich SSI. It could be seen that most of the students could plan and monitor their studies, but some students could not evaluate metacognitively in the ME-rich SSI. To explain the process how students have derived benefits from the ME-rich SSI, students' responses in the semi-structured interview were analyzed. These findings could be important to account for the improvement of metacognitive regulation among students. For example,

Student 9 said, *'Using mind-map during lesson is useful in checking if I know the previous understanding.* [Metacognitive indicator – monitoring] *I can cross-check the understanding after the activities in the lesson. I can check if my understanding is correct.* [Metacognitive indicator – monitoring] *I am not very familiar with metacognition. Some parts are quite complicated. But I understand the concepts. I changed my learning strategies.* [Metacognitive indicator – evaluation] *For normal biology lesson, I just go back to the book again. This time, I will go to internet to find reference.* [Metacognitive indicator – planning] *For presentation, it helps me in metacognitive skills. Classmates mention the positive and negative side, questions and opinions can help me understand. I have some evaluation. I look at the past paper and fill in the missing boxes. My understanding was not thorough, and I didn't master all* *concepts.* [Metacognitive indicator – monitoring] *The Metacognitive task helps me evaluate my performance to see whether knowledge was mastered or not. Also it serves the purpose of re-understanding my own way of learning if it is feasible. If can't master, should I change the study method? This helps me better understand my study methods.* [Metacognitive indicator – evaluation] *During lesson, I don't understand a certain part. My study method is just read and read. My parents reminded me to reflect my ineffective method in studying. I then reflect and go to watch the video in the link and they help me in studying.* [Metacognitive indicator – planning] *I look at the past paper again, I think this method is better than just read and read.* [Metacognitive indicator – monitoring]'

Student 9 demonstrated cycles of metacognitive planning, monitoring and evaluation in his learning within the setting of a metacognitive-rich SSI. He pointed out that he didn't know the term metacognition in the past. Metacognition is an important element of a self-regulated learner (Zimmerman, 1989). The result of the thematic analysis in identifying metacognitive indicators suggested that students in the intervention group were more active within the metacognitive-rich SSI setting. They actively collected information by various means and checked their cognition regularly so as to monitor, reflect or evaluate their learning progress and understanding of the contents.

Another explanation to the higher metacognitive regulation among students in the intervention group could be the result of the inquiry nature of SSI. The integration of SSI and metacognition were discussed in different studies (Palinscar & Brown, 1984; Mevarech & Kramarski, 1997; Azevedo et al., 2008). Eggert and colleagues (2013) pointed out the importance of providing metacognitive support to students who face high cognitive demand while dealing with a complex

SSI. Students have to process different information with different skills including argumentation and decision-making. These researchers conducted a study to assess the interaction between metacognition, decision-making and self-regulated learning. As they reported, there are limited studies about how metacognition interacts with SSI.

Moreover, as reported in the study of Spellman and colleagues (2016), by applying SSI to the teaching of this ecology topic, students could have more opportunities to actively think from multiple perspectives, which in turn improve students' social-ecological problem solving. With the inquiry nature of the ME-rich SSI, students in the intervention group could have more opportunities to decide about the usefulness of the different materials collected, and how they could make use of those information to understand the issue and formulate appropriate arguments or views based on different standpoints in this ecology-related SSI. Through this process, students could monitor their own learning and evaluate metacognitively in an ecology classroom.

The finding of this study also echoes the conclusion made by Seraphin's team (2012) that metacognitive activities could lead to potential enhancement of students' critical thinking and scientific literacy through an inquiry pedagogical framework in an aquatic ecology class, which help students to assess their own's weaknesses and strengths. They suggested that metacognition could lead to self-directed learning and discussion through inquiry. In the ME-rich SSI approach used in this study, it is found that the approach could produce an effect similar to the way in which Seraphin and colleagues' framework improved students' ability to assess their own cognitive and metacognitive regulation which could lead to an increase in the effectiveness of inquiry-based science education in an ecology classroom.

Lastly, students reported that there were several advantages of implementing SSI into the curriculum. Students believed that SSI could promote their thinking from multiple perspectives (18%). This could in fact be linked to the emphasis on metacognition process through which the students were expected to analyze their own thinking processes. Echoing Presley and colleagues' (2013) design of the SSI-based education framework, students with high ability would engage in more productive thinking to confront scientific ideas and social beliefs in the issue that could enhance their understanding of science from different perspectives. Dealing with different information at the same time, students may try harder to motivate their own selves and practice more effective learning strategies (Ormrod, 2010), which might also improve their metacognitive regulation.

5.2 ME-rich SSI - a context to develop self-efficacy

From the result of the 2x2 mixed ANOVA, the self-efficacy of students of the intervention group were significantly higher than the control group after the implementation of the metacognitive-rich SSI. This is confirmed by the results of the independent samples *t*-test on the gain in score on self-efficacy. Moreover, the impact of an ME-rich SSI approach on self-efficacy could be inferred from the thematic analysis of the students' interview data, which indicates the presence of the sources of self-efficacy (i.e., self-efficacy indicators, namely mastery experience, vicarious experience, social persuasion and emotional arousal). From the result, social persuasion (61%) was reportedly the most popular, followed by mastery experience (48%) and vicarious experience (32%). Kiran and Sungur (2012) conducted a study on the relationships between different sources or factors of self-efficacy and metacognition in a middle school. In their study, mastery experience and social persuasion were found to be positively related with metacognition. In their study, the dominating factor contributing to self-efficacy was tested to be social persuasion (verbal persuasion), followed by mastery experience. The finding of this study was consistent with the result reported by their study. This implies that effort could be made to boost students' self-efficacy to a larger extent by enhancing the mastery experience students gain from the ME-rich SSI approach. Wish a greater mastery experience, students could be more efficacious when dealing with the large amount of information made accessible to them both inside and outside the classroom.

To explain how ME-rich SSI could lead to possible development of self-efficacy, insights could be drawn from the thematic analysis data. After the intervention, the quantitative data suggested that students got more interested (13%), got higher/clearer aim to study better (3%) and got higher sense of participation (2%). Although the percentage of students showing this perception is relatively low, such findings may potentially reveal how the ME-rich SSI approach could lead to a higher self-efficacy and enhance students' motivation. Moreover, thematic analysis of the possible factors conducive to the development of self-efficacy reveals less equivocal outcomes. The fact that students in the intervention group recorded higher self-confidence (35%) and achieved deeper and better understanding (16%) after going through the ME-rich SSI could be associated with an increase in their mastery experience, an important source for the development of self-efficacy.

5.2.1 Effect of explicit metacognitive activities on the development of self-efficacy

In the study, students from the intervention group generally got statistically significant improvement in self-efficacy. With the focus of the intervention on metacognitive demand, the improvement of metacognitive regulation could lead to the improvement of self-efficacy. This is supported by the high correlation between self-efficacy and metacognitive regulation in both pretest and posttest. This result echoes the result obtained by other scholars in the field (e.g., Koseoglu & Efendioglu, 2015; Zhang, 2003; Cera, Mancini & Antonietti, 2013; Crede & Philips, 2001). Qualitative data from the student interviews reveal some possible reasons for the generally higher self-efficacy from the intervention group that may be due to explicit metacognitive activities. For example,

Student 6 said, *'The thinking skills (metacognitive tasks) can help me evaluate my progress step by step. In the past, I just face the notes with an empty mind. When I see difficult subtopics, I can read more and listen more to teachers…* [Metacognitive indicator – planning] *For Tai Po Kau, I know how it is important in biodiversity. I know things about wetland. I want to study better after reflection. I always want to study better but I can't because of attitude and interest. Now I have higher interest and knowing more, I think easier, I can do more reflection and I want to study better…* [Self-efficacy indicator – mastery experience] *The thinking skills reminds me to evaluate the direction of study if it is correct.'* [Metacognitive indicator – monitoring] and

Student 13 said, *'The metacognition checking is useful to consolidate my knowledge because I think immediately about the knowledge when I see the question…I did evaluation to think about if I really understand the whole topic and face the questions in HKDSE. I think I need to understand more after completing the worksheet.'* [Metacognitive indicator – evaluation]

From the interview data of the above students, they have developed better direction and attitude to the metacognitive tasks given by the teacher. Student 6 managed to recall his prior knowledge of wetland and felt efficacious about the learning in this ecology classroom. These learning outcomes were apparently related to the metacognitive regulations he had made during the learning processes. From the thematic analysis of the interview data, students from the intervention group expressed that metacognitive tasks could help them link the issue to their prior knowledge in biology (28%). This may help students feel less anxious. Moreover, the students expressed that the metacognitive tasks could provide directions about studying (24%) and provide better understanding (15%). These two benefits could be important to shape the self-efficacy of students by lowering students' anxiety towards biology. Students felt less anxious when they applied more metacognitive strategies (Gonzalez, Fernandez, & Paoloni, 2016). Such results supported the previous study of Zeidner (2014) that students may underperform if they could not make good use of their metacognitive abilities. Ghonsoolya, Khajavyb and Mahjoobic (2014) also found that self-efficacy and metacognitive ability are associated with better academic performance. But metacognition has a stronger effect than self-efficacy.

5.2.2 Self-efficacy and student's anxiety

As suggested by the literature, tasks with higher quality albeit demanding could be important to science education. Students became less interested in biology due to dissatisfaction with their high school science experience (Osborne & Collins, 2000). Lin and Tsai (2013) proposed students' self-efficacy could be improved by activities that demand high-order thinking. In this ecology classroom, the implementation of a metacognitive-rich SSI could allow students to learn outside the textbook. Different scholars suggested the importance of incorporating SSI into the science curriculum to improve the quality of science education (Sadler & Dawson, 2012; Tasci, 2015; Hatano & Inagaki, 1991). From the interview data, students suggested how SSI helped them visualize vague content concepts. This could lead to potential improvement of their self-efficacy by delivering vague ideas to them in a pleasant way and by reducing their anxiety towards the topic. For example.

Student 6 said, '*My self-confidence increases because of the real and authentic examples and case. Then I learn the concepts.* ***It is difficult to imagine how they work just by looking at the vague facts***.'; and

Student 26 said, '*SSI is useful and specific to us like whether an artificial beach should be built. I can link it to the biological concepts like biodiversity and human impacts.* ***Ecology is abstract and vague, with an issue to do, it is easier to be grasped and focused****.'; and*

Student 30 said, *'Using SSI can help.* ***Book examples are vague*** *and I need to study by myself.* ***With an issue, which is real and authentic, we can find a lot of real data and report to help us study***.'

The above student views on the lowered anxiety could be related to the fact that only one student showed emotional arousal in the interview. Emotional arousal is a negative contributor to self-efficacy. From the interview of Student 16 said, he said,

'*It is more interesting and it is not following books. There are activities like reading map and it is more interesting* ***but I felt less secured***.' *[Self-efficacy indicator – emotional arousal]*

The above interview extract exemplifies the influence of negative emotion arousal to students' self-efficacy. The thematic analysis of the interview data further suggested more possible reasons for the enhanced self-efficacy observed among students in the intervention group. Students believed that SSI could deliver curriculum content more effectively (16%) than the conventional way. With a better delivery of curriculum, the anxiety of students towards a complex topic could be reduced. The above findings echoed the findings by Cimen and Yilmaz (2015) and Gonzalez, Fernandez and Paoloni (2016) who reported that students' self-efficacy was strongly related to students' anxiety. These results also echoed Adler's team (2018) finding that students generally gained greater interest after studying the SSI. Their increased in self-efficacy was likely boosted by a reduction in emotional arousal.

As a matter of fact, there was research showing that metacognition could be used as a predictor of anxiety symptoms (Ryum et al., 2017). The potential of metacognitive regulation for students to regulate their anxiety level is reflected from the interview data. For example, Student 13 said that

'Doing mind-map can help me structure my knowledge in my mind to have clearer understanding. [Metacognitive indicator – monitoring] *The metacognition checking is useful to consolidate my knowledge because I think immediately about the knowledge when I see the question. In the past, I only do this when doing exercise but not in the lesson. When I face difficulty, I find related information on the internet.* [Metacognitive indicator – planning] *I did evaluation to think about if I really understand the whole topic and face the questions in HKDSE. I think I need to understand more after completing the worksheet.* [Metacognitive indicator – evaluation] Using SSI can help me increase self-confidence.*'*

This student's utterance could be seen as a sign of decreased anxiety. A decreased level of anxiety is also implicated by the main findings in this study that metacognitive tasks could help students to link prior knowledge and provide directions about study as discussed in the previous chapter. From the thematic analysis results, students in the intervention had developed higher self-confidence in this ecology topic (35%). Students thought it was easier to understand the topic using the ME-rich SSI approach (13%). This shed a new light on the possibility of ME-rich SSI to address the problems of low motivation and low efficacy of weaker students. This finding echoes previous studies which showed that explicit instruction of metacognition could lead to improvement in metacognition especially for low-achieving students (Brown & Palincsar, 1984; Dignath, Buettner, & Langfeldt, 2008; White & Frederiksen, 1998; Zohar & Ben David, 2008; Zohar & Peled, 2008; Zohar & Barzilai, 2013).

To summarize, the results showed that a metacognitive-rich SSI could be a possible way to promote students' self-efficacy. As reported by different studies, the two constructs are positively correlated (Aydin, 2015; Coutinho, 2008; Kanfer, Ackermann & Schmitt, 1989). How self-efficacy and metacognition relate to and influence each other is worthy of further investigation.

5.3 Relationship between metacognitive regulation and self-efficacy, and conceptual understanding in the context of SRL

The 2x2 mixed design ANOVA results indicated that students from the intervention group showed no significant difference in conceptual understanding at the pretest and posttest for both groups although there was a significant interaction effect between conceptual understanding and student groups. However, the result of independent samples *t*-test shows that there was significant higher gain in scores on conceptual understanding reported from students in the intervention group. From the mixed result, the improvement in conceptual understanding in the intervention group might not be enough to justify whether the ME-rich SSI enhance students' conceptual understanding or not. In the following, possible explanation to such a mixed finding of data will be presented.

5.3.1 Students' attitudes towards change in study strategies

A reason of the above mixed finding may be that improvement in conceptual understanding might not always be a result of higher metacognitive regulation. Dye and Stanton (2017) reported that upper-division biology students might avoid effective metacognitive strategies because of their confidence in studying. In other words, some students could show reluctance to new strategies in the metacognition process. This could limit their conceptual understanding within the study. Qualitative data from the interviews also showed that some students were reluctant to change their methods of study. It was not surprising to find that quite a number of students mentioned they would stick to 'rote memorization' in the interview. Some of them insisted to apply such traditional studying method after evaluating metacognitively. For example,

Student 11 said, '*The thinking questions didn't help me much because* ***I like rote memorizing.***'; and

Student 16 said, '***Science should rely on rote memorization.*** *My interest increased but I have reservation on performance which should depend on effort*'; and

Student 27 said, '*Not much improved to my self-confidence towards biology because now I am in F6.* ***I can only do rote memorization***.'

Summarizing the above interview extracts, the reasons for these students to avoid new strategies could be due to previous success, anxiety in changing study methods or over-confidence. The above result corresponded to the finding of Dye and Stanton (2017), who reported in their study that some students might not benefit from evaluating learning strategies and approaches due to various reasons, including persistent consideration on the efficiency of the strategy when evaluating, choosing ineffective strategies based on past success and avoiding effective strategies due to discomfort.

Wang (2015) summarized some reasons why students overestimated their performance of ability after metacognitive evaluation. She quoted studies from different scholars that students would have limited ability to evaluate their performance given a single external standard, which it is especially influential to low-achieving students. She suggested a need to provide students with a clear way of self-evaluation so as to improve learning. Moreover, it may take time for students to practice metacognition, and for a higher self-efficacy to impact on conceptual understanding. These findings may provide an explanation of the limited improvement on conceptual understanding in the present metacognitive-rich SSI setting.

However, the mixed results from the independent samples *t*-tests and the 2x2 mixed design ANOVA may indicate an improvement in the intervention group, though not statistically significant. Such improvement was reported in the independent samples *t*-test on the gain in score on conceptual understanding. This can be supported by the fact that there were some students reflecting on their learning strategies metacognitively and were willing to change their strategies. For example, Student 14 said, '*I should use more methods like LS,* ***but not the rote memorizing*** *like other biology topics.*'; and

Student 24 said, '***It is better than direct rote memorization.*** *Using this method when I study ecosystem makes me n think about SSI. I think using issues to study biology is easier.*'; and

Student 25 said, '*This can promote activity of mind. SSI and metacognition are related.* ***I just used rote memorization in the past with book****. In SSI, it will not directly tell the theory, we need to find out the common points and concepts by myself.*'; and

Student 30 said, '*My self-confidence increases because this approach can help me study science and biology. It is different from the old method.* ***This can trigger me to think rather than rote memorization.*** *I have taken a new direction to look at science knowledge.*'

Concluding the above findings, the reason that some students in the intervention group might not benefit from the metacognitive-rich SSI to enhance conceptual understanding could be explained by the fact that some students were over-confident or over-estimating their ability during self-evaluation. This could affect the achievement of a desired performance (Moores, Chang & Smith, 2006; Wang, 2015; Dye & Stanton, 2016). Moores and Chang (2009) discussed about over-confidence when a person's actual performance is lower than the expected performance, which could yield a lower performance albeit with a high self-efficacy. As discussed by Seraphin and collegues (2012), both teachers and students could have different metacognitive abilities. They both need to understand the importance of metacognition in controlling individual's beliefs and controls when reading and understanding scientific content in different sources. To improve, teachers should apply a wider repertoire to assess students' metacognition, and students have to improve their own assessment of metacognitive knowledge and regulation skills in ME-rich SSI.

5.3.2 The complicated nature of SSI

Another reason explaining the limited improvement of conceptual understanding could be due to the design of the ME-rich SSI. The complex nature of SSI could limit the performance of students. Sadler and Dawson (2012) pointed out that students might struggle with advanced argumentation practices in SSI in the study of scientific argumentation. The success of the implementation of SSI is highly dependent on the nature and quality of resources and support provided to students. In relation to this view, interview extracts from the students provide support to the above finding. Some students showed different forms of struggling in going through the ME-rich SSI. For example,

Student 3 said, '*There are too many boxes and I have to spend a long time to complete them seriously*' and

Student 8 said, '*The questions about metacognition is impressive. They are useful but I am not used to them. I have difficulty in reading a lot of sources.*'

On the contrary, some students appreciated the complex nature of SSI. In this ecology classroom, they were provided with various pieces of ecological information, ranging from news to scientific publications. Through challenging students with relevant questions, they began to regard that this

ME-rich SSI could deliver comprehensive and rich curriculum contents in a new way to assist them in learning. For example,

Student 1 said, '*It did not follow the book to teach. It had other extra information and was more comprehensive*.'; and

Student 14 said, '*The topic is about social issue and sustainable development, and it can reflect more about ecosystem. The information is less factual*.'; and

Student 23 said, '*I think my self-confidence increase because as a science student, I didn't realize I can use big environmental data (the Tai Po development) to discuss a concept. I will try this way when learning other new science concepts. In revision, with so much data, I will try to understand it but not reciting it. I can spend less time on revising.*'; and

Student 30 said, *'With issue, which is real and authentic, we can find a lot of real data and reports to help us study. Ting Kok plus project is not a familiar issue to me, but as a citizen we can think more about the importance of environmental protection after studying the biological knowledge.'*

From the above interview extracts, students apparently felt they had access to a larger pool of information and knowledge in this ecology classroom. The benefits of SSI as reflected from the thematic analysis also showed that SSI can provide a rich content to students (6%) and build knowledge in a constructivist's way (4%).

Levinson (2006) argued the incorporation of SSI could provide students with a learning experience that helps them construct their own knowledge by making decision upon ill-structured issues. When involving students' decision making, students have to be equipped with certain ability to make a decision in a step-by-step manner (Lee & Grace, 2012; Gresch, Hasselhorn & Bogeholz, 2013) Such move could pose difficulties to students and could lead to failing to deliver the expected results from the incorporation of SSI (Kortland, 1996).

Students could be overloaded cognitively when SSI are incorporated into the curriculum because they have to actively search for different information and perform different evaluation skills (Veenman, Hout-Wolters & Afflerbach, 2006). This might have led to unsatisfactory improvement in conceptual understanding despite enhancement of metacognitive regulation among students in the intervention group. Students could be overloaded by group work and other cognitively demanding tasks in the ME-rich SSI.

Another problem faced by students may be that they might not clearly comprehend the concepts underlying the issue as the SSI approach requires students to use different reasoning skills and moral judgment to evaluate and resolve the controversial issue (Lai, 2018). In particular, students have to deal with a large amount of information from different online sources to determine if they are relevant to the evaluation of the issue (Hung et al., 2013). There are reports that some students could not select appropriate strategies in decision-making about the SSI (Seethaler & Linn, 2004), and some students could not make a convincing claim with adequate argumentation skills (Lin & Mintzes, 2010; Nicolaidou et al., 2011; Sandoval & Millwood, 2005). Students might feel difficult to make use of available sources as well (Sampson & Clark, 2008; Pedretti & Nazir, 2011). As proposed by Rose and Barton (2012), secondary school science instruction emphasizes content knowledge provided by textbooks, which are mostly well-structured. When content knowledge is heavily loaded, students would not be able to engage in scientific processes to explore authentic issues. This seems to provide additional argument to the importance of incorporating an explicit instruction of metacognitive strategies in science education. Explicit instruction for developing such higher-order cognitive abilities could be the key to aid students' problem solving and evaluation of scientific information and concepts in a novel topic (Spellman et al., 2016).

5.3.3 Learning environment provided by the ME-rich SSI

From the result of the MOLE-S questionnaire, students' perception of the classroom environment brought about by the intervention could suggest a need to refine the design of the ME-rich SSI approach so as to unleash its potential to improve students' learning and conceptual understanding. From the result of the analysis of MOLE-S, it could be concluded that students in the intervention group have received higher metacognitive demands from the lesson than students in the control group. ME-rich SSI is thus expected to provide a metacognitive experience to foster the development of metacognitive knowledge and skills in exploring an issue (Efklides, 2006, 2011).

However, there seemed not to have a significant difference between the two groups in bringing up discourse and interaction with the teacher. As argued by Thomas (2002), a metacognitively oriented classroom would involve a considerable amount of discourses with the support of the teacher. The level of discourse and the role of teacher in this ME-rich SSI setting could be a determining factor affecting the effectiveness in promoting students' conceptual understanding. Apart from learning materials and the people involved, the learning and instructional environment could be a key to success in an SSI classroom. Group discussion, presentations and argumentation should be incorporated into the SSI to provide a collaborative and interactive classroom that could help cultivate fruitful discourses (Klosterman & Sadler, 2010; Zeidler, 2014). In the implementation of SSI, the importance of discourse has been extensively studied along with the development of argumentation in science education. In the SSI observation protocol developed by Topcu and colleagues (2017), a good classroom environment should allow the presentation of the issue and science content in a sequence that could bring the issue to a sharp focus. Sadler (2011) said that such development of students' ideas and inquiry into the social dimension could provide opportunities to engage students in science practice and socio-scientific reasoning when they consider different dimensions of the SSI. In the interviews, students suggested more discussions in the lessons, showing their awareness of the importance of student-student discourse. This could explain the result of the MOLE-S questionnaire that there was no significant difference in 'student-student discourse' and 'student-teacher discourse' between the intervention and control group. The above explanation is supported by the interview extracts from students. For example,

Student 16 said, '*There can be more student discussions.*' and

Student 17 said, '*I want to have whole class discussion in the class.*'

The above findings showed the desire of having more student-student discourse after metacognitive evaluation of the learning progress by some students, which echoes the suggestions by Adler and colleagues (2018) to embed metacognitive guidance into the inquiry process in science education. In their study framework, more student-student interactions were built into an online forum which aimed to enable students to collaborate and share their views through learner to learner interaction on the Internet. Such online platform could allow a delayed response time for students to think before they responded to an issue, exchanged information, and discussed and even assessed alternative perspectives of the issue. Their method could further enhance the development of metacognitive knowledge through SSI in this ecology classroom.

5.3.4 Lack of argumentation components in the ME-rich SSI

In an ideal classroom, students are exposed to a variety of pedagogies including debates loaded with epistemological or reasoning questions. Students have to prepare themselves, but students' preparation might be limited by their personal experience about decision making and argumentation. Simon, Erduran and Osborne (2006) focused on the argumentation dialogue used by 12 teachers who taught argumentation. They found that changes in students' argumentation skills were linked to teachers' classroom dialogue. The role of the teacher in encouraging reflection and developing counter-arguments was found to be particularly important. The crucial role of the teacher was also emphasized by Jimenex-Aleixandre and colleagues (2001, p.782), who concluded that the teacher needs to create "a climate of confidence which encouraged students to express and defend their opinions, combined with the use of tasks that required students to work collaboratively and solve problems". With the implementation of ME-rich SSI, the role of teacher should be strengthened to support students' argumentation so as to improve their scientific literacy. In this study, students' desire to engage in discourses and arguments is evidenced by the thematic analysis of the interview data. Students thought that the ME-rich SSI could allow them to make their judgement (6%) and build knowledge in a constructivist's way (4%). More evidences could be obtained from the student interview extracts. For example, Student 3 said, '*I need to generalize facts and study the statistic in forming stances towards the sustainable development of Ting Kok Project… I generalized research into arguments and formulate a better stance which is more persuasive in presentation. I can know better about my stance point and classmates can understand better*.' and

Student 26 said, '*I first look into the pros and cons. But science is neutral and it needs to be elaborated on the basis of evidence. I will see points from both sides then I can take a stance. I appreciate that we can take a stance freely.*'

These two interview extracts highlighted the importance of students' preparedness in this ME-rich SSI. The above findings provide further support to the finding of Dawson and Venville (2008) that SSI should be delivered along with focused argumentation training to improve students' abilities of making arguments to support claims. Students in this ME-rich SSI seemed to be aware of the quality of their arguments. With a better argumentation framework, it should be possible to further unleash the potential of the ME-rich SSI for improving students' conceptual understanding. However, combining the mixed responses towards SSI from the interview data, this study echoes the message from Sadler and Dawson (2012) that the inclusion of SSI might affect the quality of instruction and the achievement of desired outcomes despite the fact that the SSI could promote different learning outcomes in science education. Based on their meta-analysis of different intervention studies of SSI across the globe, they found that some students are struggling with advanced argumentation skills in SSI-based education (Albe, 2008). These findings imply that the ability to practice argumentation, though not the main focus of this study, might have influenced the findings of this study and the effectiveness of the ME-rich SSI.

5.4. Inter-relationship among metacognitive regulation, self-efficacy and conceptual understanding

From the data collected, the intervention could gear students toward a higher self-efficacy and metacognitive regulation. However, the improvement in conceptual understanding remained doubtful.

The result of the MANOVA study supplemented by a Pearson Correlation between the gain in scores on the three dependent variables - metacognitive regulation, self-efficacy and conceptual understanding - revealed their interconnectedness. The gain in metacognition and self-efficacy has a strong positive correlation (r = .567, p < .01), while the gain in conceptual understanding is positively correlated with the gain in self-efficacy and metacognition respectively [r = .394 (p < .01) and .273 (p < .05)] correspondingly. It can be concluded that the strength of association between metacognitive regulation and self-efficacy is large.

These findings echo previous findings by a number of researchers. For instance, Tavakoli and Koosha (2016) pointed out that self-efficacy is strongly associated with metacognitive strategies. Kanfer, Ackerman and Schmitt (1989) summarized that highly efficacious students tend to use more metacognitive strategies. Hermita and Thamrin (2015) also reported in their study a positive relationship between metacognition and self-efficacy. In comparison, the strength of association between conceptual understanding and the other two variables are small to medium.

5.4.1 Metacognitive awareness and self-efficacy

From the statistical results, it can be concluded that students' gain in score on metacognitive regulation and gain in score on self-efficacy are strongly related. With the design of the metacognitive-rich SSI, the controversial nature of SSI might be important to build student interests so that they can actively link science to social problems (Dori et al., 2003). This may help explain the positive correlational relationship between self-efficacy and metacognition in the ME-rich SSI. More support for this assertion could be derived from the interview data of student 10 is quoted as saying,

'…Before learning this topic, if I get into difficulty, I can ask my classmates and do more information gathering. ***The thinking skills help me think about solutions… I ask my classmates about things I don't understand. I didn't do this in the past. This style of learning can be applied to other difficult topics as well. There were a lot of things I can't understand. I compare others' work with my own work this time. In the past, I didn't compare.*** *I focused on marks before and now I focus on the process more. Seeing others' presentation, I think they work hard and I want to work hard too...'*

In the metacognitive-rich SSI setting, metacognitive tasks embedded in the teaching materials provoked Student 10 to actively plan, monitor and evaluate his study progress and strategies. In the interview, he shared how metacognitive tasks have provided him with vicarious learning experiences. This showed a way in which metacognition and self-efficacy are associated with each other. More support for such correlation could be obtained from the interview of student 18. He said, *'I am impressed by an article and I ask myself question. It can help me learn in other topics as well. I can see what I have missed. This reading skill can be applied to others. Teaching reading skills and asking myself questions is useful. Self-asking and self-answering - I applied this skill in doing the project. I find the endangered species and I asked if Hong Kong should conserve the habitats. I think again and reflect myself if the plan is feasible…In the past, we base on more knowledge and now issue. After lesson I find more information on the Internet and help me understand the topic easier.* ***I think it definitely increased my self-confidence because I can find and re-ensure what I didn't study or missed. It helps me question. I evaluated and reflected.*** *It enhances my awareness towards environmental issues. I will give myself questions to reflect on so as to enrich my memory of each topic. I will set questions in each topic for myself.'*

It can be seen that the increase of his self-confidence and in turn his self-efficacy might be a result of his enhanced metacognitive regulation. As reflected from the interview data, he was able to benefit from the ability of questioning and the ability to control and monitor his cognition. It seems that his control of cognition has eventually led to self-regulated learning. His ability to plan, monitor and evaluate is believed to have a positive impact on self-efficacy (Zepeda et al., 2015). Researches showed that students' confidence, task value and the ability to use cognitively selected strategies could lead to a higher self-efficacy (Pajares, 2008; Zimmerman, Bonner, & Kovach, 1996; Jacobs et al., 2002; Meece, Blumenfeld, & Hoyle, 1988; Nolen, 1988). Students' successful experiences in a complicated and new task could lead to a higher desire to accept the challenges of more difficult tasks (Cacioppo et al., 1996). Elliot and Murayama's (2008) description of students' goal orientation toward successful self-regulated learning through metacognitive planning demonstrates a similar process. Once students have mastered metacognitive planning skills, they will have higher confidence in performing a specific task. As self-efficacy is much related to the value of task (Bandura, 1986), metacognitive planning contributed to the development of self-efficacy.

Metacognitive monitoring and evaluation may play a part in the development of self-efficacy in allowing students to make decisions on successful or unsuccessful strategies in their learning process. Students could attribute success or failure to more accurate reasons, particularly the strategies they applied in the task. Dweck (1999) discussed that students' belief of intelligence are affected by task evaluation skills. Pintrich and colleagues (1991) also pointed out that students' metacognitive monitoring is important to develop students' control of learning beliefs. The belief that intelligence matters the most could be changed through metacognitive monitoring and evaluation. As self-efficacy is related to students' own perception of his or her self-belief, the ability to perform metacognitive monitoring and evaluation is likely to contribute to the development of students' self-efficacy. Therefore, a metacognitive-rich SSI approach could potentially promote students' self-regulation to achieve their goals. Then students could attribute their failure in biology to more realistic factors that they could improve other than the lack of intelligence. Moreover, from the thematic analysis of metacognitive indicators, it was found that 9 students (student 2, 4, 8, 11, 16, 17, 21, 23 and 27) could not demonstrate a complete metacognitive regulation cycle. Among these 9 students, 4 of them showed no self-efficacy indicators from their responses in the interview. On the contrary, among the other 22 students who demonstrated a complete cycle of metacognitive regulation, only 1 student showed no self-efficacy indicator from his response in the interview. Combining with the quantitative data of this study and the reports from other researchers, the hypothesis of a positive relation between metacognition and self-efficacy is supported.

5.4.2 Relationship between conceptual understanding and metacognition

The weaker correlation (r = .273, p < .05) between conceptual understanding and metacognition could be explained based on the finding on research question 3 '*What is the effect of metacognitive-rich SSI on students' conceptual understanding?'* that was discussed in the previous section. Students might avoid new strategies because of different reasons, including over-confident or over-estimation (Moores, Chang & Smith, 2006; Wang, 2015; Dye & Stanton, 2016). Moreover, as discussed therein, Blank (2000) reported limited improvement of ecological knowledge in her study of a metacognitive learning cycle intervention. Although the students could not outcompete the control group in terms of conceptual understanding, they had experienced more permanent restructuring of their ecology understanding. Evidence could be obtained from the thematic analysis of the interview data that SSI could arouse environmental awareness (7%). For example,

Student 1 said, '*Using issue to teach is good because it can stimulate student to think rather than reading facts only.* ***It can stimulate the building up my awareness about environment***.'; and

Student 18 said, '***I feel more aware about environment. It enhances the awareness towards environmental issues***.'; and

Student 21 said, '***Using issues can promote our awareness of the endangered species in Hong Kong***.'; and

Student 27 said, '***We should have higher awareness towards Hong Kong natural environment****. Many of us study the topic but didn't think about its relevance to our life. They don't understand the importance of studying such topic and they can't have the feeling and echo that. I think using SSI can link to the things I mentioned.'*

The higher environmental awareness brought about by the metacognitive SSI could be further investigated to identify how it is related to the ownership of the ecological knowledge and the promotion of long-term memory about ecology. Zeidler and colleagues (2005) said that SSI should aim to promote the development of awareness of the interdependence between science and society apart from intellectual development. From the thematic analysis of the interview data, such aim of SSI seemed to have achieved in this study. In a discussion about challenges and opportunities for environmental education in Chinese communities by Cheng and So (2017), they highlighted a lack of curriculum coherence for environmental education in Hong Kong schools. Moreover, they made recommendations on the roles of science teachers in implementing environmental education with inquiry-based teaching strategies so as to transform conventional environmental education into education for sustainable development.

5.5 Possible mediating factors for achieving self-regulated learning in ME-rich SSI

From the above analysis of students' response and the significant improvement of metacognitive regulation and self-efficacy shown by the qualitative data analysis, the relationship between metacognition and self-efficacy in self-regulated learning could be demonstrated in this study. Students could plan, monitor and evaluate in the forethought, performance and self-reflection phases. However, the result also suggests rooms for improvement in the design or the ME-rich SSI to deliver desirable outcomes, especially in conceptual understanding. From the interviews, other mediating factors are implicated, which might possibly enhance the relationship between the metacognitive regulation, self-efficacy and conceptual understanding in the SSI-based classroom. The potential mediating factors of achieving self-regulated learning includes (1) the nature of science, (2) argumentation and (3) the role of teachers.

5.5.1 Nature of science

From the thematic analysis of the interview data, students believed that SSI could deliver curriculum content more effectively (16%) while at the same time provide richer content to students (10%). This is supported by the view of different scholars that students could indeed learn better with a high-quality learning experience made possible by the setting of quality tasks which demand students to exhibit complex intellectual performance (Koh & Luke, 2009; Lingard et al., 2001; Ladwig, 2007). This fits with the nature of SSI that could enable learning of content knowledge in context. Moreover, another 18% of the respondents said that SSI could link authentic and daily examples with which they were familiar to the curriculum when they learn ecology. Presley and colleagues (2013) said authentic examples and experience could help foster students' conceptual understanding and at the same time develop students' skills. Traditional textbooks provided a well-organized but not contextualized content for students to study. SSI-based instruction could allow students to actively research into knowledge in real life contexts. Students could connect the materials that they are going to learn with the real world (Klosterman, Sadler & Brown, 2012). In this study, it was found that role of teacher and classroom environment scored lowest in the MOLE-S. Students only had limited time to engage in higher order activities and the teacher tended to teach content rather than developing students' critical thinking and cognitive skills. The reason causing such outcome could be due to the limited duration of intervention even for the intervention group, which was relatively short. Limited time could be a reason for lower scores. Both the teachers and students felt they did not have enough time. This is consistent with previous researches that the teacher had to struggle to place student at the center of a classroom (Aikenhead, 2006; Sadler, 2009; Saunders & Rennie, 2013). Some teachers were also afraid of losing control of the class (Aikenhead, 2006) or they felt difficult to deal with controversial conflicting views from students (Bryce & Gray, 2004).

It is worthy of mentioning that some students in the intervention group reported in the interview that the metacognitive-rich SSI could help their learning about the nature of science. This is not surprising as SSI is widely regarded as important for promoting scientific literacy (Bingle & Gaskell 1994; Sadler, 2009; Zeidler & Keefer, 2003). Indeed, the knowledge of NOS was reported as one of the four main learning outcomes of SSI (Sadler & Dawson, 2012). The knowledge of NOS influences students' metacognitive regulation and self-efficacy were reported by Peters (2010). In her study, she documented strong correlation between metacognition and self-efficacy due to the effect of nature of science and metacognitive prompts. Moreover, in the doctoral study of Parker and Kitsantas (2010) about the relationship between NOS and science self-efficacy beliefs of sixth grade students, positive effects on self-efficacy was found on his samples who received NOS instruction. He attributed such improvement to the lowered science anxiety upon receiving NOS instruction. Lee (2017) also discussed the importance of integrating the nature of science into SSI to enable students to differentiate scientific from nonscientific evidence in their formulation of decisions. Although the nature of science is not the focus of this study, the advantage of a metacognitive-rich SSI in inspiring students to understand the nature of science was reported by the students in the intervention group (9%).

Apart from the linkage between NOS and self-efficacy, the student interview data from the intervention group also revealed close relationships between metacognition and NOS. For example, in the interview of student 24, he said,

'*I am impressed by the SSI about Ting Kok, I didn't know Hong Kong has done this. I understand more about EIA and 'LEFT' tool about science and society method.*'

'EIA' is the abbreviation of environmental impact assessment which is a requirement for local developers to conduct before a development or infrastructure could be launched, while 'LEFT' tool is the abbreviation of a local ecological foot-printing tool. It was used to draw relevant environmental data from the global database. The students demonstrated proactive learning of these two terms, which were not included in the syllabus.

Apart from that, student 26 said, '*My self-confidence has increased because there is the nature of science in it. It shows the dynamic nature of science and the knowledge is tentative. In different times we have different views.*'

He mentioned the dynamic nature of science and the knowledge is tentative. Although his understanding towards the nature of science could be naive, he did show some sharp observations about the nature of science without explicit teaching from the instructor.

Moreover, student 13 said,

'*Doing mind-map can help me structure my knowledge in my mind to have clearer understanding… This can help me think step by step which is similar to doing science. Planning, monitoring, and regulating are steps which are similar to doing science and scientific investigation.*'

Student 13 mentioned the process of scientific investigation. He thought the process of metacognition (planning, monitoring and regulating) was similar to the process of scientific investigation. Although this interpretation might be naive and inaccurate, this analogy suggests that the metacognitive-rich SSI approach can benefit students' learning and thinking in science in a cognitive way.

5.5.2 Argumentation

The strong correlation between self-efficacy and metacognition may be mediated by another expected outcome of SSI – argumentation. Previous research in the literature which examined the relationships between metacognitive awareness, argumentation skills and theoretical explanations support the results of the present study. Mason and Santi (1994) investigated the argument levels in terms of metacognitive awareness in their research on fifth graders. The findings demonstrated that high levels of metacognitive awareness were accompanied by the argument development levels. From the thematic analysis of the advantages of SSI, it was believed by the students to provide a better classroom environment (12%), arouse their own environmental awareness (7%), allow them to make judgements (6%) and let them build knowledge in a constructivist's way (4%). This in fact was related to another focus of the SSI about interest, motivation and argumentation

(Sadler & Dawson, 2012). It is generally agreed that SSI can be utilized as a mean to put argumentation, informal reasoning and decision making of students to a better focus (Topcu, Mugaloglu & Guven, 2014). Different researchers made different use of SSI in science education to achieve their desired research outcomes. SSI could provide a context to promote argumentation and informal reasoning. Hence it should also have the potential to develop students' metacognition and self-efficacy through the reasoning process. This claim is supported by the qualitative data collected from the interview by Student 3 who illustrated this point by saying,

'Doing presentation requires me to do more research and present my own findings. I need to generalize facts and study the statistic in forming stances towards the sustainable development of Ting Kok Project. I can add my views to it and it is easy to remember the concepts. Boxes about red tides, algal bloom can help me recall the facts because they are useful to me. I prefer teachers to do the grouping, this is more effective. I have difficulty in distinguishing the geographical facts about Ting Kok, Tai Mei Tuk. I am not very sure about their locations. I use google maps to check where they are. [Metacognitive indicator – planning] *I need to talk with my group members in the evaluation box on the worksheet. I need to tell how my metacognition changed. I would like to have fieldtrip and I can know more about Lung Mei. Is Lung Mei Beach bringing social benefits to the district? It is subjective and I need to go there.* [Metacognitive indicator – monitoring] *I generalized research into arguments and formulate a better stance which is more persuasive in presentation.'*

Like NOS, engagement of students in argumentation about SSI could provide a rich context for students to think metacognitively. Hence it may help develop students' metacognitive thinking skills. Student 3's utterances showed how the SSI has motivated him to perform better argumentation under his metacognitive control. His metacognitive controls were also motivated by the metacognitive tasks in the worksheet. A complete metacognition cycle – planning, monitoring and evaluation (Blank, 2000) was demonstrated. With his enhanced metacognitive regulation, his self-efficacy was likely to increase due to the social persuasion and mastery experience he was exposed to in such metacognitive-rich SSI setting.

As stated in the previous section that students in the intervention group showed a preference for more discussion or discourse. It could be seen that the metacognitive-rich SSI provoked the desire of discourse between students. Newton, Driver and Osborne (1999) provide several compelling reasons for explicit teaching of argumentation in science classrooms. Dawson and Venville (2008) summarized how discourses in SSI could help construct verified scientific knowledge. They reported that argumentation is the discourse of those who practice science. This fits with Tanner's findings (2012) that students could learn better if they were encouraged to think and learn in the way of real biologists. This could be a useful strategy to integrate concepts across different levels of organization and complexity. In reality, scientists communicate their propositions to other scientists in different occasions. They then provide evidence to support their propositions, which is subject to peer reviews by expert scientific media and communities.

Moreover, teachers should also make explicit instructions in order to help students argue more effectively in class discussion. Lin and Mintzes (2010) conducted a study which suggested explicit instruction in argumentation skills could have positive effects on student learning, particularly on high-achieving elementary school students. Students were asked different guiding questions about the establishment of a National Park. They needed to establish claims and warrants, construct counterarguments, offer supportive arguments, and provide evidence for each one. The results showed that the high achievers appeared to master more argumentation skills about the specific SSI while the low achievers lagged in their ability to master skills in constructing arguments, counterarguments, and rebuttals and in generating supportive evidence for a claim.

On the contrary, students of lower ability could struggle due to the lack of conceptual understanding about the issues. Zohar and Dori (2003) found that such difference could be reduced by explicit instruction with longer teaching duration to provide weaker students more opportunities to practice argumentation. It follows that the rather limited improvement to conceptual understanding students from the intervention group showed could be due to the design of the ME-rich SSI. Apart from being metacognitive-rich, the design of such approach should consider the importance of discourse and the teacher's role in developing students' argumentation skills to fully unleash the advantage of the implementation of SSI in science education.

5.5.3 Role of the teacher

Some of the characteristics of successful inquiry teaching could be found in different research studies. The first characteristic is the implementation of inquiry to promote active involvement of students (Collette & Chiapetta, 2002). Different studies showed that science inquiry could enhance students' science cognitive abilities and academic emotions (Mistler-Jackson & Songer, 2000). Students could make use of their cognitive ability to perform more high-order thinking and make their own decisions in scientific inquiry. In group discussion that aims to arouse discourse among students, teachers could move around from group to group to act as a resource person for students.

Students also prefer teachers to ask more challenging questions (Abi-El-Mona and Abd-El-Khalik, 2006), give more nonverbal support, and be more understanding, friendly and be able to apply daily lives context to teaching (She and Fisher, 2002). The lack of feedback to students by the teacher could also lead to unsatisfactory improvement in conceptual understanding (Zepeda et al., 2015). In this ME-rich SSI, however, the above quality of a successful teacher could not be wholly demonstrated as reflected by the students' views on classroom environment in their MOLE-S questionnaire. The inadequate discourse might have led to a less challenging classroom.

Different researchers urged teachers to increasingly use challenging questions to promote students' ability of argumentation, and understanding and decision making on SSI (Patronis, 1999; Simon, Erduran & Osborne, 2006; Simon and Maloney. 2007). Through such practice, students will have the chance to integrate scientific knowledge and argumentation. With questions that are challenging with opposing arguments, students can clarify their thought in class discussions (Simonneaux, 2001). Peer group discussion is believed to serve the purpose of enhancing students' knowledge and their awareness of values related to SSI. The finding of this study also suggests the importance of the role of teacher. The role of teacher is crucial in integrating appropriate pedagogy and assessments into the curriculum to evaluate and enhance student's learning. To teach SSI, the teacher should be knowledgeable enough about science ideas in the issue (Zeidler, Applebaum & Sadler, 2011). This quality of teacher is important to lead students' discussion within the issue. The teacher should provide ideas to students in the classroom without being the sole knowledge authorities (Dolan, Nichols & Zeidler, 2009). The best scenario is that all parties could respect different views generated from the SSI despite the fact that this would pose difficulties and challenges to teachers.

Teachers also need more flexibility and development in order to put assessment into practice and create a learning environment to engage students in interactive learning activities consistent with the "psychological, philosophical, historical and sociological conceptions of the growth of scientific knowledge" (Adams, Gitomer & Duschl, 1995). Dawson and Venville (2008) pointed out that the teacher should encourage reflection in the lesson. As students in the intervention group responded that a metacognitive-rich SSI could provide a better learning experience (12%), the improvement of the dependent variables of the study could be closely related to such setting. Although the change of role in teacher was not very obvious in the study, none or only a few interview respondents opined that the instructor was didactic. Consistent with the suggestion by Seraphin's team (2012) that teacher's role should change from a unilateral knowledge deliverer to a leader and a research director, the metacognitive rich SSI could improve classroom environment to a certain extent. This is important to promote social persuasion and vicarious experience to sustain and promote students' self-efficacy.

Tidemand and Nielsen (2017) conducted a study in Denmark to reveal the difficulties that a biology teacher could face in incorporating SSI in biology. Although different studies could show the benefits on students' motivation and science literacy by using SSI (Dori, Tai & Tsaushu, 2003), many teachers have a low awareness of SSI in teaching and many teachers have failed to incorporate them in their teaching (Lazarowitz & Bloch, 2005) because of its challenging nature. The main challenges of incorporating SSI include; (1) Lack of teaching materials and time to prepare; (2) Limited capacity to respond to students' idea; (3) Lack of confidence or teacher-efficacy in handling discussion especially about ethical issues; and (4) Student assessment.

Lee and colleagues (2006) pointed out that many teachers harbored a content-centered interpretation of SSI. Similar to Hong Kong, the examination-oriented curriculum design in Korea hindered the potential of utilizing SSI in science education. In the examination of Hong Kong and Korea, the assessment focus relied on the mastery of biological content rather than the competencies to interpret socio-scientific knowledge.

Apart from ecology and conservation, the biology syllabus includes quite a number of suitable topics that could generate ME-rich SSI and teachers could incorporate those contemporary issues to enrich students' learning experience. Potential candidates including biotechnology, human reproduction, immunology and diseases are worthy of consideration by biology teachers. This could cause a shift of the focus of the SSI to factual biological content. There is a need of professional development to change the teachers' mindset and their ability to utilize SSI in their teaching. To maximize the benefits of the SSI approach, more effort and studies should be devoted to the role of teacher and teachers' training on the use of the metacognitive-rich SSI intervention.

In summary, the qualitative data collected from this study revealed that the effectiveness of ME-rich SSI in promoting metacognitive regulation, self-efficacy and conceptual understanding might be enhanced if the possible mediating factors identified could be addressed. Based on the findings discussed therein, a revised conceptual framework of the study is shown in figure 15 on the next page.

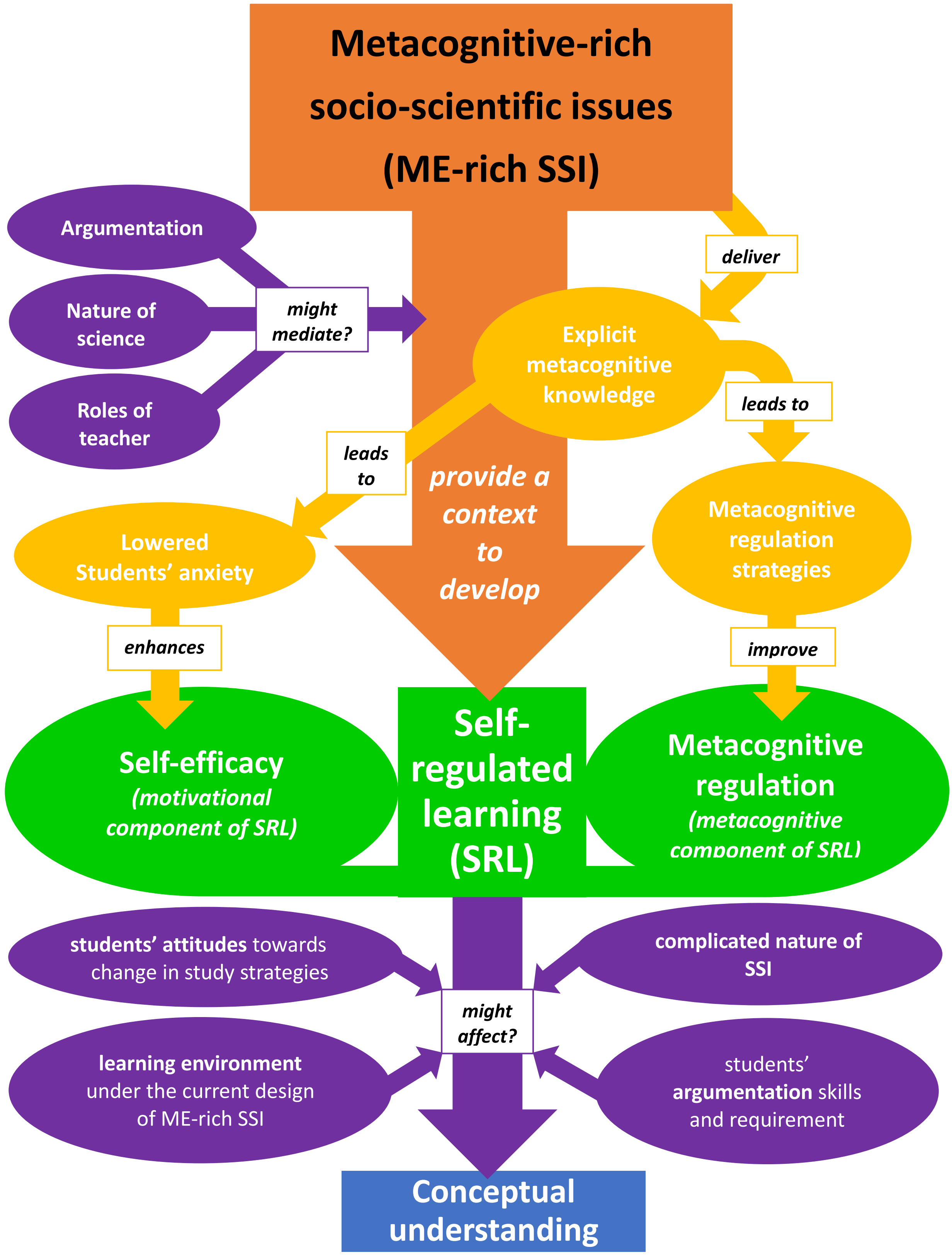

Figure 15. A revised conceptual framework of the study

5.6 Educational implications

This study concluded a wide range of benefits by utilizing ME-rich SSI in an ecology classroom. Such framework could link metacognitive regulation and self-efficacy with local biology syllabus to initiate SRL which could possibly enhance students' conceptual understanding. In general, the findings in this study supported that metacognitive regulation and self-efficacy work reciprocally. Education researchers should not abandon metacognitive regulation nor self-efficacy in the research of SRL and SSI. This view is in line with the finding of Yerdelen-Damar and Pesman (2013) in which self-efficacy could mediate the relationship between metacognition and conceptual understanding in physics. As found from this study, some students might avoid effective learning strategies due to various reasons, teachers should encourage students to refrain from ineffective learning strategies and help them become more aware of different learning strategies in order to fully unleash the power of ME-rich SSI teaching and learning experience.

In this intervention, explicit metacognitive instructions were embedded throughout a local ecology topic. This instructional method seemed to be effective in promoting students' learning in an ecology classroom. The framework of intervention could be a possible model for biology teachers to consider when incorporating SSIs into their curriculum. Bringing in SSIs to the classroom could be challenging (Zepeda et al., 2015). Teachers might not address SSIs in classrooms despite the benefits (McGinnis & Simmons, 1999). Also, students often tend to focus more on content knowledge rather than on the teaching and learning process (Yilmaz, 2011). Training and development should be provided to teachers to expand teachers' capability of utilizing complex SSIs in science education.

From the qualitative data, the researcher found that quite a number of students got higher interested and aware of environmental issues through learning experiences provided by an ME-rich SSI teaching environment. There were calls for more discussion stressing the importance of taking stances. These suggest the possibilities of making good use of students' motivation to align science education with real-world situations through ill-structured SSIs. As seen from the result of the MOLE-S questionnaire, a metacognition-oriented classroom environment should include more discourses and supports from teachers. This suggests a need for education researchers to investigate into how to help teachers to make the classroom environment more metacognition-oriented. Students' interest in biology could be promoted through enriching the current curriculum with appropriate use of SSI. By fulfilling students' cognitive and motivational needs in an ecology classroom, an ME-rich SSI approach could further enhance students' SRL. As such, this study could contribute to the improvement of biology education.

5.7 Limitation of the study

Being a part-time doctorate student in Hong Kong and a full-time secondary school teacher, the researcher had faced a number of limitations in conducting this study.

As a sole researcher, the researcher designed, refined and implemented the quasi-experiment in his serving school. In a highly examination-oriented culture, the researcher cautiously scheduled the intervention of this SSI-based classroom so as to avoid disturbance to the tight teaching schedule. As random assignment of students to the intervention and control groups was impossible, intact classes had to be used for comparison. The small sample size and limited choices of classes were major limitations of this study, which render the findings difficult to be generalized.

To draw maximal insights from the quantitative data and reduce the threats to validity to a minimum, the researcher applied both the 2x2 mixed ANOVA and the independent-samples *t*-test to analyse the gain in score on different dependent variables to compare the differences between the intervention and control groups. Additionally, the quantitative data was triangulated with the qualitative ones obtained from individual interviews with all the students from the intervention group.

Moreover, the instruments used to collect quantitative data - the MOLE-S and the MSLQ, which were self-reported. Although it was fairly convenient to administer and analyze the data collected, they may be subject to reliability and validity issues. There might be bias in students' perception of their own selves, which might render the validity of the collected data questionable. In fact, this issue is common to all studies that rely upon students' self-reported data as the sole source of evidence. Such limitation nevertheless was addressed by careful selection of reputable and well validated measures, such as the MOLE-S and the MSLQ and as the main instruments for this study.

This study utilized a researcher self-designed pretest and posttest to assess students' gain in score on conceptual understanding before and after the intervention. The reliability and validity of such assessment could also affect the representativeness of the data collected. In order to increase the validity and representativeness of the result, further research should be conducted by utilizing a standardized assessment tool such as that used in national examinations. Moreover, a well-developed ecology test inventory from other studies could also be used to address such validity issue.

Furthermore, the short duration of the intervention is definitely a limitation as the development of such attributes as metacognition may entail long-term efforts and practices. As reported by Avargil and colleagues (2018), the time needed for metacognitive strategies intervention varied from few weeks to 3 and 4 months. This study is at the short end of this duration spectrum, which makes it difficult to study the delayed effect of metacognitive instruction as suggested by Mevarech and Kramarski (2003). As an improvement, the duration of this kind of intervention study could be extended, involving possibly more topics in biology education. With careful planning and implementation, the effects of ME-rich SSI could be fully explored.

Due to the exploratory nature of this study, only the intervention group received explicit metacognitive instructions. Students in the control group might be deprived of the possible benefits derived from such instructional framework and style. As supported by the findings of this study, the researcher will consider making use of extra metacognitive instructions in future teaching to promote students' SRL.

Lastly, an issue arising from the qualitative methodology that the researcher was at the same time the instructor of the course, which might lead to biases in interpreting the interview data Maxwell (2005). The researcher conducted the interviews, thematic analysis and coding all by himself owing to obvious constraints such as time, funding and the limited capacity of the teacher as a sole researcher. As a sole researcher, inter-rater reliability could not be applied in analyzing the qualitative data.

Nevertheless, potential biases were minimized by fully transcribing the verbal interview data before coding and making the thematic analysis and coding process as transparent and detailed as possible. The researcher also conducted the coding process in two main rounds to ensure accuracy. Full transcriptions of interview data were included in appendix E.

Due to the limitation of time and resources, qualitative data were only collected from the intervention group, but not from the control group. In order to have a whole picture of how metacognitive-rich SSI would change the learning and teaching in the classroom, the interview protocols should be administered to the control group as well in future studies to contrast those data collected from the treatment group. The researcher could also invite observers such as fellow teachers or researchers in the university to conduct lesson observations so as to provide more objective views on the ME-rich SSI learning environment rather than relying solely on the perceptions of the students.

5.8 Recommendation for further research

The sample in this study only included male students due to the fact that the researcher was teaching in a boy school. To validate the potential advantages of ME-rich SSI based on this study targeting only male students, there should be researches about how the ME-rich SSI framework could affect both male and female students' metacognitive regulation, self-efficacy and conceptual understanding. This kind of study could also include more schools, including single-sex schools and co-educational schools so as to fully validate the possible benefits of ME-rich SSI to students' learning in science education. Moreover, researchers should also consider diversifying the research methods to include non-experimental study. Longer intervention periods and greater sample sizes may be considered to develop a more macroscopic view on how changes may occur in students. All these could further increase the validity and trustworthiness of the ME-rich SSI framework. From the study, it was found that the metacognitive-rich SSI approach could generate different effects on metacognitive regulation, self-efficacy and conceptual understanding. The present study analyzed possible interactions among various components of SRL in the context of SSI.

Echoing the finding of Zepeda and colleagues (2015), this study also revealed the possibilities that one SRL component might benefit other components. Further studies are needed to explore how these variables may impact one another. To explore the possible interactions between different components in the ME-rich SSI, further research should examine potential factors that mediate the interactions among dependent variables and how they influence each other. As argued in the preceding sections, these factors include (1) the nature of science, (2) argumentation, and (3) the role of the teacher.

Indeed, Presley and colleagues (2013) recommended educators to consider enriching learners' experience by confronting them with ethical dimensions and the nature of science. Moreover, their framework also stressed the importance of teacher attributes in an open-ended SSI-based instruction. They described an effective SSI-based teacher as being able to transform the uncertainties in the SSI classroom into meaningful students' experiences. Their recommendation coincides with the finding about potential mediating factors involved in ME-rich SSI. This is not surprising because this study also make reference to Presley and colleagues' framework (2013) in the design stage, yet with a different focus on the SRL construct. The effects of the above mediating factors on the interaction between components of SRL in an ME-rich SSI environment were not well-documented. Further study could be done to address the ability of metacognitive-rich SSI to integrate with the nature of science, to foster argumentation and to promote a shift in the teacher's role in science education.

Peters and Kitsantas (2010) concluded that teaching science with unrelated facts could be problematic in science education which could hinder the development of scientific knowledge. There has been calls to incorporate metacognitive elements into science education (Thomas, 2009). According to Abd-EL-Khalick and Akerson (2009), explicit metacognitive strategies could develop teachers' knowledge of NOS more effectively. However, the views from teachers were not broadly considered and investigated (Zohar, 1999). In SSI-based teaching, the mindset of the teacher could be important in affecting students' learning (Adi & Nir, 2013). Therefore, the mindset of teachers to link SSI and the development of students' metacognition is very important to the success of an SSI-based classroom. Therefore, there is a need for researching into teachers' continuous professional development to train efficacious teachers to be experts in designing instructions to facilitate student experiences in an SSI classroom, and at the same time to consider students' metacognition and motivation issues. Only if a teacher could understand the processes of SRL which involved metacognition, and its interplay with self-efficacy could the teacher address students' narrow focus of biology learning on rote memorization, leading possibly to improvement in conceptual understanding.

5.9 Conclusion

In conclusion, an ME-rich SSI approach could promote students' metacognitive regulation and self-efficacy in learning biology to a noticeable extent through providing an ME-rich learning environment. The possibility to reduce academic anxiety by metacognitive activities might be a contributor to the promotion of self-efficacy. The improvement of metacognitive regulation could be a consequence of the fact that ME-rich SSI could promote scientific reasoning and higher-order thinking. SSI education could allow students to integrate scientific and non-scientific knowledge to help students understand a particular topic. This could motivate students by making learning more interesting and relevant to daily life. Decision-making and value judgment is an important learning outcome of SSI-based education so that students have the ability to reflect on their reasoning. Students can develop skills important for citizenship such as altruism, compassion, etc., which is important to develop the character of a citizen in nowadays Hong Kong and the world, apart from academic achievement.

With the possibility of evidence-based argumentation, the ME-rich SSI could eventually lead to a better ground of science education in catering to students' emotion and cognition. With a better learning environment and more active roles of teachers as facilitators, providing discourse and feedback to students in the ME-rich SSI, students would have a better chance to achieve SRL through developing their metacognitive regulation and self-efficacy.

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