Self-Directed Learning in Science Education: Explicating the Enabling Factors

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Abstract: The notion of self-directed learning (SDL) has gained prominence in many education institutes around the world. However, few studies detail the specific enabling factors that could foster SDL in primary and secondary school science education. Focusing on this gap, we engaged in a mixed methods study that examined 17 schools in Hong Kong, consisting of 10 primary and 7 secondary schools. Altogether, 1,538 students from 55 classes and involving 53 teachers participated in the study which ran from September 2014 to June 2015. Building upon four key SDL representation models, we first developed our three-dimensional SDL conceptual framework to guide our analysis of the specific leadership-, teacher-, and student-related factors that could foster SDL in science education. Five key enabling factors are described.

Introduction

The notion of self-directed learning (SDL) is not new. Originally conceptualized as a desired competence in adult education, Knowles (1975, p. 18) defined SDL "a process in which the individual takes the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes". In recent years, however SDL has been recognized as an important element in school age students' learning due to the realization that many students today study merely for the sake of examinations (that is, being "exam smart") but lack the skill to monitor one's own learning, and rely heavily on the guidance of teachers (Hew & Cheung, 2012).

In a survey of 431 employers representing more than two million employees, almost 60% of employer respondents rated secondary school graduates as being deficient in skills related to SDL (Partnership for 21st Century Skills, 2006). The results for college graduates were even more depressing – only 25% of employers rated four-year college graduates as excellent in SDL. Even though the survey results focused on the USA workforce, and thus may not be generalized to other parts of the world (no such large scale study has been conducted in Asia), the results do highlight concerns about graduates' ability for SDL, and consequently their readiness to enter the workforce in the long term.

In this study, we address the central question: *What are the specific factors that could foster SDL?* Previous research on SDL has often been limited to the college or university contexts. Few studies detail the specific enabling factors of SDL in primary and secondary school. Focusing on this gap, we engaged in a mixed methods study to extract specific factors that could foster SDL in science education. A total of 1,538 students and 53 teachers from 17 different schools in Hong Kong participated in this project. We chose science education as our context of implementation because of its importance to the global economy, and problem solving ability which is considered one of the key 21st skills. We argue that science education is not merely about facts acquisition, but a process of inquiry which requires students to evaluate and reflect on their own thinking related to the activities of planning, measuring, observing, analyzing data, and examining evidence. Self-directed learning as an instructional strategy provides for a large degree of student choice and allows students to formulate, investigate, and reformulate problems and solutions of their own design (van Merrienboer & Sluijsmans, 2009). Hence, when self-directed learning is implemented with appropriate support for students, it can help students develop the inquiry process critical to science education.

The rest of the article is organized as follows. First, in the conceptual framework section, we describe our three-dimensional model for understanding SDL. We used the conceptual model to guide our analysis of the specific factors that could foster SDL in science education. We then describe the methodology of the study, followed by the results and discussion. We conclude by highlighting some limitations of this study and several suggestions for future research.

Conceptual framework

Many models have been proposed to understand SDL, beginning with Mocker and Spear's *Two Dimensional Model* in the early 1980s to a more recent model from Song and Hill (2007). We found that, often, what is lacking in one model can be found in another one. Therefore, in this section, in order to develop a more comprehensive three-dimensional model to help us understand the factors that might foster SDL in science education, we drew largely upon the writings of Brockett and Hiemstra (1991), Candy (1991), Garrison (1997), and Song and Hill (2007). These four works were selected because they appear to be among the most cited works in SDL. However, other writings were also consulted where necessary to provide supplementary or background information. Our SDL conceptual model includes three connected dimensions: personal attributes, autonomous processes, and learning context (see Figure 1).

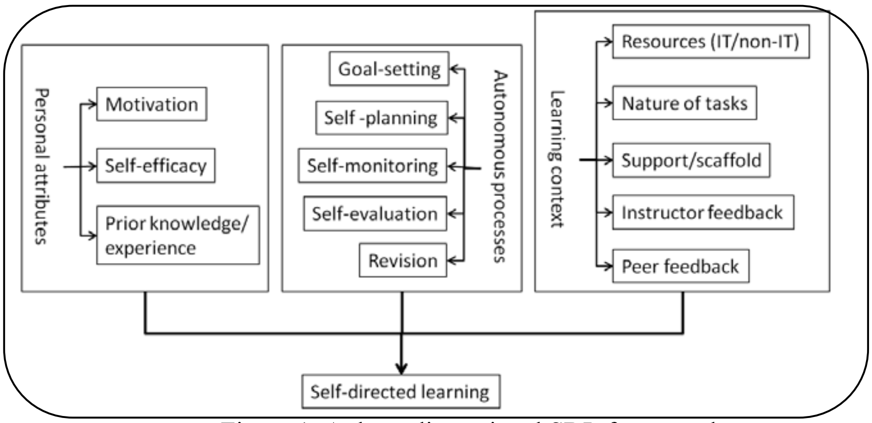

Figure 1. A three-dimensional SDL framework

Personal attributes play an important role in the initiation and maintenance of SDL. They refer to the characteristics an individual (teacher or student) bring to a learning context (Song & Hill, 2007). More specifically, personal attributes include an individual's motivation (Brockett & Hiemstra, 1991; Garrison, 1997), self-efficacy (Brockett & Hiemstra, 1991), and prior knowledge of the content area or prior experience with the learning context (Song & Hill, 2007). Motivation may refer to intrinsic or extrinsic factors. Individuals will have a higher intrinsic motivational state if they perceive that SDL will meet their personal needs (values) and affective states (preferences) (Garrison, 1997). Extrinsic motivation (e.g, reward) is equally important, as it is found to directly enhance an individual's intrinsic motivation to engage in activities (Yoo et al., 2012). Self-efficacy or the belief of one's ability to accomplish a task will also help inspire and sustain an individual's engagement in SDL (Garrison, 1997). An individual's prior knowledge of the content area or prior experience with SDL will also affect his or her self-direction in learning (Song & Hill, 2007). Individuals who have engaged in SDL before will find it easier to diagnose their learning needs, and formulate learning goals as compared to those who are unfamiliar with it.

Autonomous processes refer to the individual's freedom of choice in SDL (Candy, 1991). Specifically, learner autonomy can be manifested in the processes of goal-setting, self-planning, self-monitoring, self-evaluation and revision (Brockett & Hiemstra, 1991; Candy, 1991; Garrison, 1997; Song & Hill, 2007). Some possible indicators of each process are presented in Table 1.

Table 1: Possible indicators for autonomous processes

Process	Description of possible indicators
Goal setting	• Students identify own learning goals & learning activities
Self-planning	• Students plan for the detailed decisions and arrangements associated with own learning
Self-monitoring	• Students manage their own time • Students monitor their own learning strategies • Students adjust their own learning pathway as they progress
Self-evaluation	• Students are aware of the assessment criteria • Students critically evaluate work according to set criteria
Revision	• Students revise their work based on the feedback received from their teacher or peers • Students reflect and apply what they have learnt to new contexts

Learning context focuses on environmental factors and how these may impact the level of SDL provided to the learner (Song & Hill, 2007). There are various factors in a learning context that can impact a learner's SDL experience; these in particular include resources (IT or non-IT), nature of the learning tasks, support or scaffold provided, instructor feedback, and peer feedback (Song & Hill, 2007). Resources can take different forms which can be parsimoniously grouped into IT (information technology) resources (e.g., Internet sites), and non-IT resources (books). Students, for example, can use Google or Yahoo! search engines to independently access additional reading materials. Another set of elements in the learning context that can impact a learner's SDL is the nature of the learning tasks, and the support given. Open-ended tasks are activities such as problems or questions that have more than one possible solution, or answer. Such activities lend themselves very well to SDL because they can help spur learners to consider various perspectives, search for different answers, and evaluate them. Since not all students are familiar with SDL, support or scaffold should be provided by the teachers. For example, asking students to create a Know-Want-Learn (KWL) chart in which they list what they know; what they wish to know; and later what they have learned can increase student learning (Campbell & Campbell, 2009), as well as metacognitive skill (Tok, 2013), an essential skill that can facilitate SDL. A KWL chart can also guide student independent thinking as it facilitates the personal pursuit of learning through exploration of the topics that students want to know. Finally, although SDL focuses primarily on the individual learner, external feedback still plays an important role. Feedback is central to student learning because it can point out errors and suggest areas for improvement so that students can move their learning forward. Both instructor and peer feedback are useful. A teacher's feedback is useful because it helps to focus students' discussion on the topic, prevent possible conflicts in the discussion, and provide useful pertinent information, while peer feedback allows students to share their views more openly (Hew, 2015).

Method

We conducted a mixed methods study using the three-dimensional SDL framework (figure 1) as an underlying factor model to analyze and extract the specific leadership-, teacher-, and student-related elements that could foster SDL. Altogether, 17 schools in Hong Kong participated in this funded project that ran from September 2014 to June 2015 (see Table 2). A total of five professional development workshops were conducted for these 17 schools. Each workshop had a specific theme for teachers to better understand the different aspects of SDL through sharing from experienced educators and hands-on activities. The specific themes included: (a) what is SDL? (b) learning and assessment design, (c) learning analytics, (d) drawing conclusion for scientific investigation, and (e) sharing of useful tools and strategies. Besides these five professional development workshops, 13 cluster meetings were also held. In these meetings, school teachers from the same cluster (e.g., north-west zone) discussed their SDL plans with the university project consultants and with other teachers.

During the cluster meetings, theoretical and pedagogical suggestions, as well as practical exemplars were given by the University project staff to teachers. In addition, teachers who were more experienced in SDL implementation acted as models to guide and review their SDL plans learning design? i.e. web-based teaching plan. In addition, various onsite training and support sessions were also conducted. From September to November 2014, the University project staff members visited participating schools and conducted teacher and student training workshops on the use of an interactive and assessment platform (iLap) (see Figure 2).

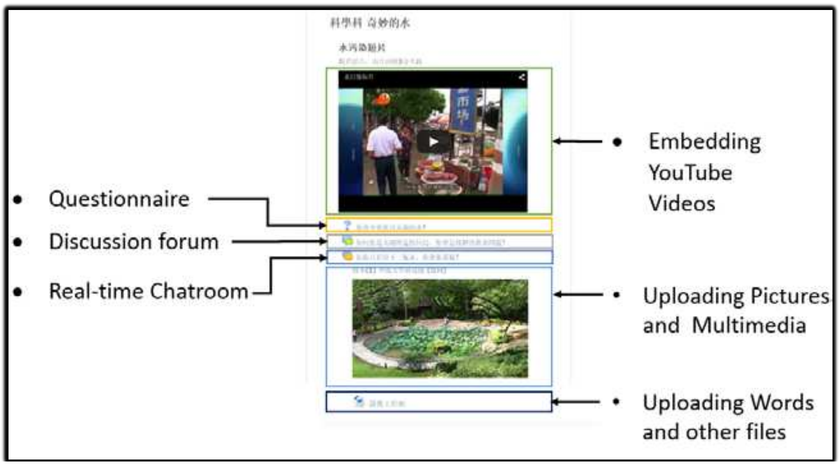

Figure 2. An interactive and assessment platform (iLap)

Specifically, iLap (interactive Learning and assessment Platform) is a Moodle-based Learning Management System (LMS) which contains various tools such as *mind maps* for students to express individual understanding for concepts learnt, *wiki pages* for students to share their learning, *blogs* for students to reflect and share what they had learnt, *discussion forums* for teachers to monitor students' understanding of concepts, and *knowledge forums* for teachers and students to engage in collative inquiry. Onsite SDL co-planning (n=24) and lesson observation (n=18) sessions were also conducted throughout the duration of the project. These sessions focused on helping teachers in SDL implementation, notably goal setting, self-planning, self-monitoring, self-evaluation and revision. With the guidance of the University project staff, the teachers of each participating school collaborated and contributed a lesson unit that incorporated the key stages of SDL in science education. The school then hosted participants from other schools in the same cluster to attend a peer lesson observation session, as well as a debriefing meeting where principals, teachers and University project staff were present to review the SDL implementation.

Of the 17 participating schools, 10 good practice schools were further selected based on a panel of three University project staff. The three staff members were responsible for all aspects of the project from beginning to end such as providing professional development workshops for teachers, attending cluster meetings, onsite lesson observations, and interviewing principals, teachers, and students. These 10 schools were chosen based on ability of their lessons to promote scientific inquiry and sustaining SDL such as enabling students to identify learning strategies to achieve the learning goals, to set the standards for the achievement of their learning goals, to formulate questions and generate relevant inquiries, to reflect on their learning and initiate gathering of feedback from teachers and peers, and to apply what they have learnt to new contexts. In this study, we are interested to address the following question: *What are the specific factors found in these 10 good practice schools that could foster SDL, as compared to the other schools?*

Table 2: Summary of the 17 schools

School	Level	No. of classes involved in SDL	No. of students involved in SDL	No. of teachers involved in SDL	Principal participation**
School A	Primary	2	53	2	2
School B	Primary	4	98	4	3
School C*	Primary	2	51	3	5
School D*	Primary	4	120	4	5
School E*	Primary	4	94	4	2
School F	Primary	2	80	2	2
School G*	Primary	5	145	5	3
School H	Primary	3	88	3	4
School I*	Primary	5	149	5	6
School J	Primary	4	117	2	4
School K*	Secondary	5	127	2	3
School L*	Secondary	2	64	4	3
School M	Secondary	1	30	1	4
School N*	Secondary	4	116	2	4
School O*	Secondary	4	124	2	2
School P*	Secondary	2	28	4	6
School Q	Secondary	2	54	4	3

*denotes good practice school; **principal participation refers to the number of times principals participated in project activities such as attending workshops, and open class observations.

Data collection and analysis

Observation of science lessons

Altogether a total of 34 science lessons were observed, two lessons in each of the 17 schools. During observations, a record of events that included the lesson objectives, lesson sequence, types of IT and non-IT tools used, and roles of the teachers and students were kept. The analysis of data proceeded alongside the collection of observational data. Preliminary analytic notes were jotted down and provided inputs for the subsequent interview sessions after each lesson.

Interviews with teachers and principals

After each lesson observation, debriefing interviews with the teachers were held. The main purpose of such interviews was to understand the teachers' reasons for planning and implementing certain activities, reasons for using IT and non-IT tools, roles of the participants, and procedures to engage students. In addition, the teachers were asked to discuss the problems they faced in the lessons with respect to scientific inquiry and SDL, and how they might address these problems. The principals from each school were also interviewed twice for about one hour each, before and after the project. The list of topics generated for the purpose of these interviews included: objectives of the school with respect to SDL and scientific inquiry implementation, personal views of SDL and how IT may foster it, and roles of the principals or administrative structure to facilitate the project implementation. The interview data were audio-recorded and transcribed for data analysis using Corbin and Strauss' (2008) grounded approach.

Focus group discussions with students

After each lesson observation, 5 students on average were chosen from each school for the focus group discussions. The list of topics for the interviews included: students' understanding of SDL, and the use of resources and how they facilitated SDL and scientific inquiry. The students' focus group data were also audio-recorded and transcribed for data analysis using Corbin and Strauss' (2008) grounded approach.

Findings and discussion

Taking the three-dimensional SDL framework (figure 1) as an underlying factor model, the main findings highlighted five key enabling factors that fostered SDL in science education: (a) the nature of tasks, (b) support or scaffold for teachers, (c) teacher motivation for SDL, (d) students' prior content knowledge, and (e) principal leadership behaviors.

Probably one of the most important factors that distinguished the good practice schools from the others was the nature of the student tasks. We found that schools with greater success in promoting student SDL (e.g., students identifying learning strategies to achieve the learning goals, formulating questions, or applying what they have learnt to new contexts) tended to utilize more *open-ended inquiry activities with real-life relevance*. The results of this study support Douglass and Morris' (2014) finding that teachers' use of real world experiences was a key factor that helped students' SDL. These activities were related to specific science principles found in the curriculum; however, they required students to apply these principles that have some real-world significance. For example, School C (a good practice school) gave students the task of building the strongest fan with the voltage being held constant. Students in groups were observed planning various experiments involving different materials, as well as the number of fan blades in an attempt to outdo other groups. Another good practice school, School P gave students the task of water filtration:

> Teacher A: I wanted students to do SDL on water pollutant, water purification and sewage treatment. Student brought their own pollutant to school and polluted the water. They had to classify the pollutant into soluble, insoluble or microbes. The next lesson they had to *purify the water and drink it*. They pored over their textbooks and even passive students sent me WhatsApp to ask questions. They designed the setup with their own apparatus. They ran filtration followed by distillation. Students were very happy for this whole activity.

School E (another good practice school) gave students the task of building a 15cm paper bridge strong enough to hold heavy things. Students in groups had to engage in self-planning, self-monitoring and evaluation, and revising their bridge designs in order to achieve the set goal. Through these processes, students were able to learn several interesting things about paper:

> Student B: I learnt that creased paper cannot be reused. Also, a light paper can be strong enough to carry the weight.
> Student C: I am amazed that thin paper can withstand the heavy weight, folded paper can be strong.
> Student D: We achieved the goal. We managed to place 6 cans of Cola on the bridge.
> Student A: I find learning from textbooks is boring, but doing SDL by ourselves is much more interesting.

On the other hands, most schools that relied on text-book type activities were not able to promote students' interest and effort for SDL as much as the good practice schools.

Teachers play a pivotal role in determining the success of any learning endeavor. Since almost all teachers were not familiar with the notion of SDL at the beginning of the project, support for (and support among) teachers was absolutely essential. Specifically, we found that teachers in the good practice schools were more eager to work with the University project staff, as well as teachers from other schools in co-planning the SDL lessons. These co-planning activities served two important purposes: they bolstered teachers' self-confidence in running the lessons, and they helped the teachers share useful resources and ideas. During the co-planning activities, teachers particularly needed support with respect to the following three areas: (a) pedagogical knowledge of SDL concerning the processes of goal-setting, self-planning, self-monitoring, self-evaluation, revision, and ways to assess students' work, (b) technological knowledge of tools such as how discussion forums work, and (c) the interplay between SDL pedagogical knowledge and technological knowledge. For example, the use of video recorders and forums afford the processes of self-monitoring and self-evaluation because since students could revisit the recorded materials and reflect on them:

> Teacher R: Students can view the work of their classmates and learn from others. The teacher can also view the recorded materials and provide feedback. These would not be possible in a conventional lesson.
>
> Teacher C: Using iLap, students could record their whole science experiments. This enabled students to review and amend their work.

Another factor that could promote SDL was the teachers' motivation for doing it. Not all teachers (including the good practice schools) were motivated in SDL for science education at the beginning of the project. Some teachers simply participated because they were asked by their principals to do so. Indeed, we found no significant differences between the good practice schools and the other schools in terms of the mere number of classes involved in SDL (Mann-Whitney $U = 17.5$, $Z = -1.791$, $p = 0.073$); the number of students involved in SDL (Mann-Whitney $U = 20.0$, $Z = -1.464$, $p = 0.143$); the number of teachers involved in SDL (Mann-Whitney $U = 20.0$, $Z = -1.533$, $p = 0.125$); and principal participation per se (Mann-Whitney $U = 25.5$, $Z = -0.952$, $p = 0.341$). There were also no significant differences the good practice schools and the other schools in terms of the number of teacher login (Mann-Whitney $U = 17.0$, $Z = -1.757$, $p = 0.079$); and student login to iLap (Mann-Whitney $U = 15.0$, $Z = -1.952$, $p = 0.051$).

However, we found that as the project progressed, more teachers in the good practice schools became more motivated in fostering SDL among their students. How did this come about? The reasons for these were mainly twofold: (a) an increase in the teachers' sense of competence or self-efficacy in designing SDL lessons, and (b) a desire to try something different. According to the Self-Determination Theory of motivation (Deci & Ryan, 2000), a strong sense of competence helps increase an individual's intrinsic motivation to accomplish a particular task. Teachers mainly gained the sense of competence as they worked with the University project staff, as well as teachers from other schools to co-plan the SDL lessons. Recall earlier our observation that teachers in the good practice schools were more eager to participate in such co-planning activities compared to the teachers from the other schools. These teachers were prepared to receive feedback, and in doing so gained confidence and competence in implementing the lessons in their actual classrooms.

Teachers in good practice schools were also more willing to try a different way to teach science. Essentially, these teachers were willing to release control of the lessons to their students rather than being the sole information provider. In other words, teachers who believed that their students could learn on their own had greater motivation in fostering SDL:

> Teacher B: You need to trust the students and let them loose. I've learned to let the students lead the class. Using SDL, I don't have to prepare all the lesson materials, and I talk less.

Another teacher was observed allowing her students to plan and design for the science experiment by themselves in groups. The teacher did not intervene even though some of the designs were not appropriate. Often when teachers released control of the classroom, many were pleasantly surprised to see their students more engaged in the lessons, and learned better than or equally well compared to the usual teacher-conducted teachings:

> Teacher H: I saw students learning on their own and questioning each other's opinions.
>
> Teacher C: Students are generally interested in SDL. They showed greater understanding of the topic learned in the school exam. Compared to other non-SDL based topics, the students' performance in this SDL-run topic was very big.
>
> Teacher F: Students were more engaged when they had the autonomy to do their own planning and research.
>
> Teacher T: I found that students wish teachers to talk less and they themselves do more. I'm surprised that students prefer SDL and they learned more from this approach.

An individual's prior knowledge of the content area can also affect his or her self-direction in learning (Song & Hill, 2007). We found students who were more versed in the subject content tended to be more engaged in SDL. They were able to ask more interesting questions, monitor their learning progress, and make better sense of the science experiment findings. They were able to better evaluate the validity of the Internet resources assessed. Students who are stronger in the topics are also individuals who like the subject more; hence they are usually more proactive in class. Being proactive in classes is frequently cited as a means to promote SDL (e.g., Douglass &

Morris, 2014; Yazedjian et al., 2008). On the other hand, students who were weaker in the subject content were not very sure about how to proceed in the lessons, and they relied on their teachers for guidance and help:

> Teacher S: I've a class of weaker students. Although they were interested in the topics, their SDL effort was limited. They did not know how to find the answers themselves, and they needed help from the teacher.
>
> Teacher C: I assigned stronger students to different groups so that they can guide the weaker students.

Therefore, in order to promote SDL among students, it would be helpful for teachers to spend some time teaching students basic information or concepts about the topics concerned. We also found that certain principal leadership behaviors to be another key enabling factor associated with SDL implementation in the good practice schools. Specifically, principals and teachers in these schools had the same desire to try out the implementation of SDL in science education, and the desire to make it work. Through this shared understanding, the Principals, although not always closely involved in every detail of the students' SDL implementation, played a vital but indirect role by ensuring that teachers were given time-off to attend the workshops and co-planning lesson sessions:

> Principal L: I gave them priority in arranging time table/ schedule. I helped carve out common time for the teachers do co-planning/ meeting.
>
> Principal M: I decreased the teachers' workload. The relevant teachers were allowed to do lesson planning together or observe each other's lesson.
>
> Principal C: Additional resources may be more time for teachers as they have fewer lessons. For hardware, we were promoting e-learning and we had iPad already, no additional resources were allocated. We had a new e-learning classroom already.
>
> Some principals also granted teachers additional support in terms of extra teaching assistants:
>
> Principal Y: Extra teaching assistant and technician were arranged for lessons, especially for the experiments.

We also found that having some form of accountability for teachers to plan and develop SDL lessons to be very helpful. We found that principals of good practice schools tended to engage in more frequent teacher monitoring activities such as by asking teachers to share their SDL stories (successful or otherwise) in professional development sessions within school or with other schools, observation visits to classrooms, and regular meetings with the teachers. Such activities served as a tool to exert pressure on teachers to think more carefully of the SDL lessons they intend to implement:

> Principal L: Let the teachers involved to share learning with the school (be it success story or failure). I monitored the progress of the project through regular meetings with the teachers. On some occasions, I also observed their SDL lessons.

The Principals also granted teachers the autonomy to change some of the assessment methods. For example, instead of merely relying on traditional methods of assessment such as pen-and-paper examinations, some teachers utilized peer assessment and student presentations to evaluate their students' SDL work.

Conclusions

In this study, we address the central question: *What are the specific factors that could foster SDL?* We engaged in a mixed methods study to extract specific factors that could foster SDL in science education. A total of 1,538 students and 53 teachers from 17 different schools in Hong Kong participated in this project which ran from September 2014 to June 2015. Five key enabling factors were found: (a) the nature of tasks, (b) support or scaffold for teachers, (c) teacher motivation for SDL, (d) students' prior content knowledge, and (e) principal leadership behaviors. These factors relate mainly to the learning context and personal attributes elements shown in Figure 1. Interestingly, the mere use of resources (IT or non-IT) did not appear to foster SDL. Probably the most important person to ensure successful SDL implementation in a classroom is the teacher. The results of this study suggest that teachers play a critical role in planning for the right type of activities that could engage students (i.e., *open-ended inquiry activities with real-life relevance*), and teachers have to be self-motivated to implement SDL. We believe these factors are paramount to the success of SDL implementations. This is not to say that processes such as student self-planning, self-monitoring, or self-evaluation are not important; however, these processes appear to be dependent on the nature of the tasks, as well as the teachers' motivation for SDL in the first place. For example, a task that is closed-ended with only one simple solution would not lend itself very well to the need for students to plan, monitor or evaluate other possible explanations or answers. Neither would a teacher who desires to control every element of the class activity be expected to achieve success in SDL because such a behavior hinders the students' autonomous processes of self-planning. The Principals appear to play an indirect role by developing the teachers' instructional capability, giving teachers the autonomy to implement appropriate assessment methods, and monitoring teachers' progress so that teachers at the frontline of teaching are better supported to implement SDL. Students, on the other hand, appeared to play a somewhat "passive" role as far as the *goal-setting of SDL topics* are concerned. This is not very surprising given that schools in Hong Kong are expected to complete their pre-determined science topics in the syllabi in order to prepare students for high-stakes examinations. The pressure to score high on high stakes examinations, along with the need to cover a vast scope of content material within a limited amount of time, often creates a daunting challenge for any SDL implementation (Hew & Cheung, 2012). Very often, the pressure on the students to progress to the next topic or activity supersedes the need to stay with the students' level of interest and curiosity regarding the specific topics (Bodin, 2008).

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Acknowledgments

This research was funded by the HK Education Bureau School-based research project fund. We thank all the participating schools.