Seamless Hybrid Science Learning: Streamlining the Techno-Pedagogical Designs for Wider Diffusion

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Background

Seamless learning is when a person experiences a continuity of learning, and consciously bridges the multifaceted learning efforts, across a combination of locations, times, technologies or social settings (Sharples et al., 2012; Wong, 2015), ideally with the support of one-mobile-device-per-learner (1:1) settings (Chan et al., 2006). Over a decade of work, our team's research and practice of the pedagogical model of seamless science inquiry learning (SSIL) has yielded impressive results. Since the successful proof-of-concept in a seed school in 2008 and 2009 (Looi et al., 2009; Seow et al., 2009), the initial pilot in a primary school (which took place between 2010 and 2013) (Zhang et al., 2010) produced data showing that the students enrolled in SSIL lessons performed significantly better in the open-ended questions in formal assessments as well as data showing improvement in higher-order thinking skills (Looi et al., 2014) and self-regulated learning (Sha et al., 2012). The learning model was diffused to 10 schools by 2015.

Despite successful implementations in those 11 schools, there were key issues in the earlier teaching toolkits that hindered direct and efficient scaling up to a larger pool of schools, For one, the teaching toolkits were originally developed around 24×7, 1:1 setting. Not all students in the local primary schools, however, possess their personal devices which can be used for their learning. To address this issue, we embarked on a follow-up, practice-oriented project to derive alternatives beyond the Bring Your Own Device (BYOD) model. This chapter constitutes a descriptive study on the follow-up project which was carried out between 2017 and 2018. That is, the positioning and the scope of this chapter are more descriptive than evaluative.

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Specifically, the role of social media in connecting students' cross-contextual learning efforts in seamless hybrid learning will be explored and explicated.

Literature Review

Seamless learning has been identified as one of the advanced learning approaches that can address the needs of twenty-first century learners (Looi et al., 2010; Sharples et al., 2012). With the salient characteristic of bridging multifaceted learning efforts across a variety of learning settings, the intention is to nurture a habit-of-mind in students to continually carry out the trajectories of learning-unlearning-relearning, and learning-application-reflection through recontextualisations of previously constructed knowledge (Wong et al., 2015).

Seamless learning is well-aligned with many other learning notions that educational researchers have been advocating over the past decades, such as hybrid learning, inquiry learning, experiential learning, self-directed learning, collaborative learning, authentic learning, blended learning, flipped classroom, critical/creative thinking, personalised learning, lifelong learning, etc. (see Wong (2015, pp. 10–14) for a comprehensive discussion on the relevancies between these learning notions and seamless learning). Some of these learning approaches may inherently suggest that learning across multiple contexts yet has not foregrounded the key feature of "bridging". For example, the situated learning construct put forward by Brown et al. (1989) has often been used to guide the design of single-setting activities (such as outdoor mobile learning trails). What researchers and practitioners often ignore is a rise-above argument in the stated paper that a constructed concept "will continually evolve with each new occasion of use because new situations, negotiations, and activities inevitably recast in new and more densely textured form" (p. 33). This argument encapsulates the essence of seamless learning. In turn, seamless learning can be regarded as a meta-learning construct that informs the designers of all the other learning approaches to design cross-contextual and bridged learning processes.

The notion of seamless learning was incepted into the context of mobile learning by Chan et al. (2006) which advocated the use of mobile technology in 1:1, 24×7 setting to facilitate individual students' ongoing, cross-contextual seamless learning. This seminal paper launched the line of research on and practice of mobile-assisted seamless learning which has later been spread to more than 40 countries, with science being the most popular domain that seamless learning has been applied to (Wong, 2015). Over the years, there has been a gradual shift of researchers' perceptions on mobile-assisted seamless learning from a technology-driven perspective (e.g., Hwang et al., 2008; Ng & Nicholas, 2007) to a curriculum design perspective (Looi & Wong, 2013; Obisat & Hattab, 2009) to the fostering of a learning culture (Milrad et al., 2013; Toh et al., 2013).

The earlier perception of having 1:1, 24×7 (i.e., personal devices as the "learning hubs" (Zhang et al., 2010) of individual students) as a mandatory enabling condition for seamless learning has been challenged in recent years. Rather than taking it as a special form of 1:1 mobile learning, more recent literature argues that seamless learning is a modern learning notion at its own right – as an aspiration (Sharples et al., 2012), a habit-of-mind (Wong & Looi, 2011) or as a set of metacognitive abilities (Sharples, 2015). Thus, alternative technological support models have been proposed, such as the “division of labour” (i.e., using different devices, computer sets or even non-digital tools available at different locations) model (Wong, 2012; Wong & Looi, 2011) and the use of social media (Charitonos et al., 2012; Laru & Järvelä, 2015).

Social media are increasingly used for supporting students’ communicative and creative endeavours (Greenhow et al., 2009). Social media support process-oriented learning by promoting student-student and teacher-student interactions. More importantly, social media afford situating of learning in multiple contexts through the same social network. For science learning, science teachers may create topical social media items to solicit student responses in and out of classroom, or encourage the students to generate social media of specific curricular themes, or on any day-to-day encounter that triggers the students’ curiosity. The posting of such student artefacts does not necessarily mark the end of the artefact generation process (Wong & Looi, 2010). Instead, leveraging the reply feature, the social media can be transformed into a social mediator for subsequent cycles of collective reflection and (re-)production (Lewis et al., 2010), social meaning making (Wong et al., 2010), or knowledge co-construction (So et al., 2009). Furthermore, designing seamless learning processes around social media would free the students from relying on 24×7 access to their personal devices, as typical social media spaces are accessible by multiple platforms or devices (i.e., the “division of labour” model of seamless learning).

Broadening Adoption of Seamless Learning

The reported study was informed by the academic field’s re-conceptualisation of seamless learning as a learning approach at its own right, rather than a special form of mobile learning which must be materialised with a 1:1 setting (Wong, 2015). To address the above-stated challenges in further diffusion, we strived for:

1. Adapting the pedagogy and design principles for less reliance on 1:1 access;
2. Streamlining the design principles in order not to overwhelm the teachers and yet preserve the essence of SSIL.

For achieving the first goal, an alternative techno-pedagogical model was proposed that combines social media and multiple devices such as school and home computers, and schools’ or family members’ handheld devices. Individual students may switch between these devices at their convenience to access to a common social media space for SSIL activities. To ensure sustainability of the model, we did not develop a new platform. Rather, we guided the teachers in sourcing for suitable existing online tools to facilitate the implementation of their lesson designs. This is known as "division of labour" model (Wong & Looi, 2011) in the seamless learning literature. Our focus was on lesson redesign, which leads to the second goal.

Regarding the second goal, three sets of design principles were indeed proposed in our team's prior publications respectively, namely, Zhang et al. (2010), Wong (2013), and Looi and Wong (2013), with six to eight principles being laid out in each set. In this follow-up project, the design principles were streamlined into five salient points: C^2FIP (Connectivity of learning spaces, (socio-)Constructivist inquiry learning; Formative assessments with student artefacts; leveraging resources in Informal settings; Personalised learning). Teachers were guided to develop new lesson plans informed by C^2FIP for enactment given the resource availability of neighbourhood schools.

The five principles are elaborated below:

- Connectivity of learning activities across contexts. Make the learning process cross-contextual, not just encompassing formal and informal settings but also in both individual and social settings, and both physical and digital environments. The student artefacts created in one activity can be fed into subsequent activities. The learning experience will become more holistic and authentic.
- Socio-Constructivist inquiry learning: Facilitate an interplay of individual and collaborative inquiry learning. Encourage diverse "ideas" from the students during various learning activities, and help them connect ideas or pieces of knowledge (e.g., between concrete and abstract knowledge, between prior and new knowledge) through various means such as concept mapping. Make students' diverse thinking visible and therefore shareable, and later synthesise the knowledge.
- Formative assessment: Different forms of student artefacts created at various learning activities can be used for formative assessment. The teacher may design for systematically fostering the students' peer and self-evaluation skills. This not only about "learning how to learn" and the nurturing of critical thinking, but also for mitigating teachers' load in reviewing student works in a long run.
- Leveraging resources in Informal settings: The students' out-of-class, day-to-day living spaces may offer authentic learning resources and therefore make their learning more relevant and meaningful. Examples include incorporation of appropriate online resources, designing mini-activities with parental/family involvement, facilitation of out-of-school learning trails at suitable sites.
- Personalised learning: Incorporate different learning modalities to suit different learning styles, and allow flexible learning pathways for individual students whenever possible. The learning experience should be student-centred, and perhaps encourage interest-driven learning out of class (i.e., individual students to connect their hobbies with formal science learning), and group students with similar interests together to stimulate informal peer learning.

Method

We worked with three primary schools in Singapore for implementation over two academic years. Our intention was to guide the participating teachers in piloting the revised SSIL model in selected lesson units (2–4 lesson units per school). Four cross-school professional development (PD) sessions were also conducted for the participating teachers to share their designs and enactment experiences, and co-construct new teaching strategies.

Before the beginning of the first-year intervention and before the second-year intervention respectively, the participating teachers selected their pilot class levels and curricular units to design and implement the SSIL lessons. Table 1 summarises the key information of the implementations carried out in the three participating schools. In total, seven student cohorts were involved in the study. The cohorts are differentiated by school, year and level, e.g., school S1's Primary 4 (or P4 in short, 4th Grade) students (from two classes) in year 2017 is considered one cohort. One or two lesson topic(s) were selected to be designed as SSIL lesson(s).

Each SSIL lesson lasted for 2–3 weeks with intertwining in-class and out-of-class, and physical and online activities. To implement each lesson topic, the teachers sourced for one or two social networking tools (as shown in Table 1) for the students to share and discuss their artefacts. All lesson plans required students to use computer or handheld devices with Internet access at home to carry out certain home-based learning activities on stipulated social networking platforms (see Table 1) at times. About 5% of the participating students whose families did not have the access to the required Information and Communication Technology (ICT) tools were allowed to stay back at the schools after class to perform the social networking activities at computer labs. In addition, during some of the in-class lessons where students were required to work in groups for digital artefact creation and/or online activities, school-owned tablets were loaned out to the students.

A qualitative descriptive study on the lesson enactments was carried out for us to yield in-depth understanding of whether and how the design principles of C^2FIP could be materialised. The research question that guides the descriptive study is:

RQ: How might the implementation of SSIL lessons at the participating schools impact the students' learning experience and the teachers' instructional practices in the aspects corresponding to the SSIL design principles of C^2FIP?

To address the research question, the following set of qualitative data were collected for analysis,

- Semi-structured pre- and post-interviews with selected students (one high-, one medium- and one low-progress student per class)
- Semi-structured pre- and post-interviews with all participating teachers
- Video and audio recordings of in-class lessons
- Student artefacts posted online and peer discussions

Table 1 Summary of implementations carried out in the participating schools

School & year	Classes & teachers	Number of students	Lesson topic (month of enactment)	Social networking tools used
S1, 2017	S1P417-1 (T11) & S1P417-2 (T12)	56	Light and shadow (July)	Padlet, Google Classroom
S1, 2018	S1P518-1 (T11) & S1P518-2 (T12)	53	Cells (February) Human systems (April)	Padlet
S2, 2017	S2P417-1 (T21) & S2P417-2 (T22)	43	Light and shadow (May) Heat (September)	Padlet
S2, 2018	S2P418-1 (T21) & S2P418-2 (T23)	50	Light and shadow (April) Heat (July)	Nearpod
S3, 2017	S3P417-1 (T31) & S3P417-2 (T32)	59	Heat (July) Human digestive system (September)	MC Online[a]
S3, 2018	S3P318-1 (T32) & S3P318-2 (T33)	59	Materials (April)	MC Online
	S3P418-2 (T34) & S3P418-3 (T35)	69	Heat (July)	MC Online

[a]MC Online is a Singapore-based Learning Management System which was deployed in many local primary schools during the time the study was carried out. The Social Learning Wall module with social media features of MC Online had been adopted by teachers at School S3 for the purpose of implementing their SSIL lessons

(Sx = school IDs; P3xx-y/P4-yP5-y = class IDs, with xx denoting the year, y denoting the semester, and P3, P4, P5 denoting third, fourth and fifth Grade respectively; and Tzz = teacher IDs)

Findings and Results

Student Practices of SSIL

We uncovered important and somewhat consistent patterns across all three schools in students' practices of SSIL. This was done through applying (qualitative) constant comparative method (Strauss & Corbin, 1990) of students' online posts and peer comments, one-to-one interviews and class recordings. With a simple coding scheme that comprises the codes corresponding with the five design principles of C^2FIP, we categorised the patterns/findings around these principles to see how the application of individual principles in the SSIL lessons have (or have not) transformed the ways the students learned. Some of the evidence are conceptually or operationally overlapping across multiple themes (design principles). We categorised the evidence in this way to make a better sense of the impact of the five design principles.

Connectivity of Learning Activities across Contexts

The teachers designed their lesson plans which largely adhere to the cycle of (optional) "flipped learning at home" → "in-class learning engagement" → "out-of-class observations/applications" → "online social reflection" (i.e., peer comments and knowledge co-construction). Such learning flows had effectively guided the students through the process of "recontextualisation" in their learning journey.

Some of the participating teachers (T11, T12, T21, T32) indicated during the pre-interviews that they had experiences in implementing flipped learning (Flipped Learning Network, 2014) in the past. Thus, they incorporated such activities to their SSIL lesson plans, which had also influenced other participating teachers in their subsequent lesson designs. For example, a SSIL lesson may begin in students being instructed to view a relevant YouTube video or research online on a given topic at home prior to the first in-class lesson. In the second year of study, to tackle the issue of students not paying the right attention on the key information to pick up from the materials, the students were required to find answers to some guiding questions by the end of the activities.

For example, in class S3P418-2, after being exposed to the basic concept of heat in the classroom, the students were tasked to take a picture at home or download a photo from the web that captured an example to show how heat was transferred, created graphical representations of the underlying mechanism or explaining it in their words, and shared them on the Social Learning Wall of MC Online to stimulate further discussions. The two examples in Fig. 1 demonstrate how the students created multimedia artefacts to demonstrate their understanding in the concept in focus.

A side benefit of such learning flows is that it had resulted in the students' greater engagement in learning as the lesson designs broke the "usual patterns" of regular science classes. As one teacher described,

> The engagement level was higher when I did seamless learning. It wasn't only because in and out of class, but during the lesson itself. ... They anticipated, what are we doing today, why are we doing this. ... I thought through different activities, we got the students to be very engaged, they felt very excited on what is coming up next. I asked some of them to give me feedback. They enjoyed the activity, and would rather have this activity rather than teacher just telling them what to do. (Teacher T11, post-interview)

Socio-Constructivist Inquiry Learning

The students were actively learning in the informal setting through online portals. They co-constructed knowledge by posting and commenting on their peers' works. That is, they made their ideas sharable for comparison and scrutiny, which led to negotiation of meaning. The benefit of carrying such activities online was articulated by a student as below,

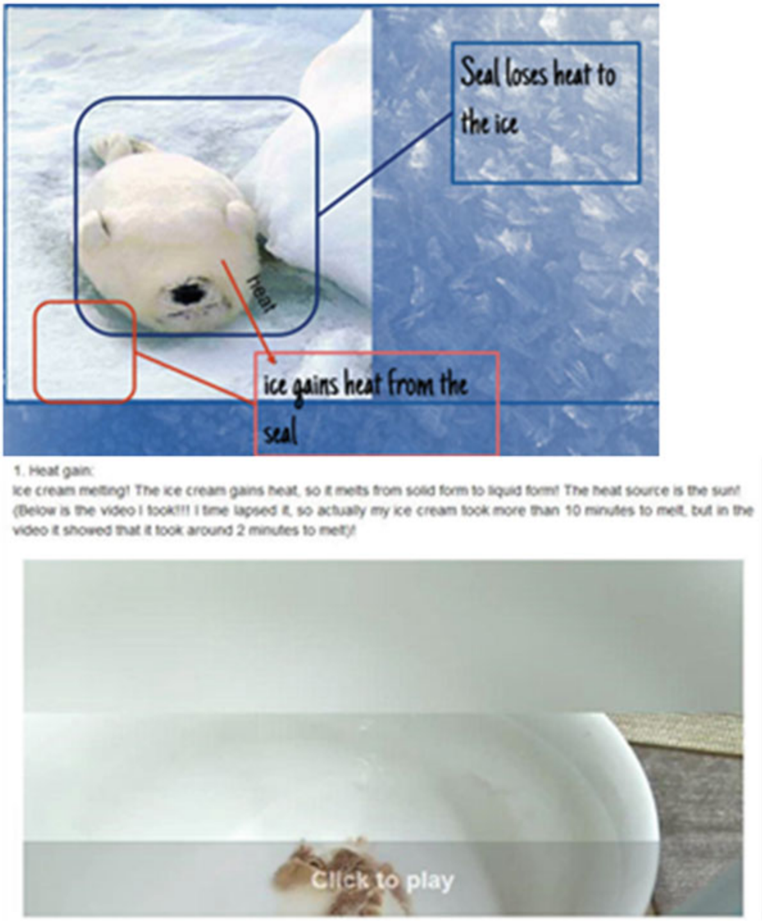

Fig. 1 (Top) a graphical representation on heat transfer with a web image; (bottom) a self-made video with caption to elaborate heat transfer (from class S3P418-2)

> The online portals enabled me to get the answer faster as I did not need to wait for classroom discussion. It was also interesting to read my friends' comments. (A student from class S1-P417-1, post-interview)

Examples of idea sharing and peer comments are given in Fig. 2. They are taken from the "heat" lesson at the class S1P417-1 where the students were instructed to identify examples of heat sources.

Fig. 2 Students' idea sharing and peer comments in the "heat" lesson at S1P417-1

Cross-Contextual Formative Assessment

Various types of student-centred activities that required students to develop and share ideas, opinions or artefacts in the class-wide social space (either posting them online or presenting them in the classroom) have effectively served as the means for formative assessments. This is because the peers were then being encouraged to scrutinise their views, compare alternative views from classmates, or provide feedback to improve their works. As the students deemed online social learning spaces as being semi-formal and low stakes, they were more willing to tinker and express diversified opinions.

> They get to go online to discuss. To them it's like chit chatting with their friends, less scared to make mistakes because it's in an informal setting. (Teacher T24, post-interview)

Figure 3 presents two screen captures that illustrate such observations.

Leveraging Resources in Informal Settings

Most SSIL lesson designs required the students to collect data out-of-class which constituted rich resources for their subsequent deeper learning. Even if some of the student-generated materials were flawed, these would become the basis for peer review and knowledge co-construction (Wong et al., 2010). The examples in Fig. 1 are two types of such data collected in informal settings. Another task under the same lesson required the students to conduct interviews with two family members or neighbours by asking them to compare the temperatures of the plastic handle and the metal blade of a pair of scissors, and to explain why the temperatures are different (see Fig. 4).

An unexpected learning gain took place where a teacher-student dialogue was focused on how to identify credible sources or verify the information during the students' web searches (an informal resource) as one of their SSIL learning activities. This constituted an opportunity to learn a topic related to new media literacy.

T31:	There are some reliable sources, textbook, MC online resources, yes, reliable because we check them. But where else? If you check internet it is also somewhat reliable. But how to make sure the information you check from the internet is reliable?
Student1:	Just don't search Wikipedia
Student2:	eah don't' search Wikipedia
T31:	Okay, Student3?
Student3:	Go to many websites and see whether the answers are the same.

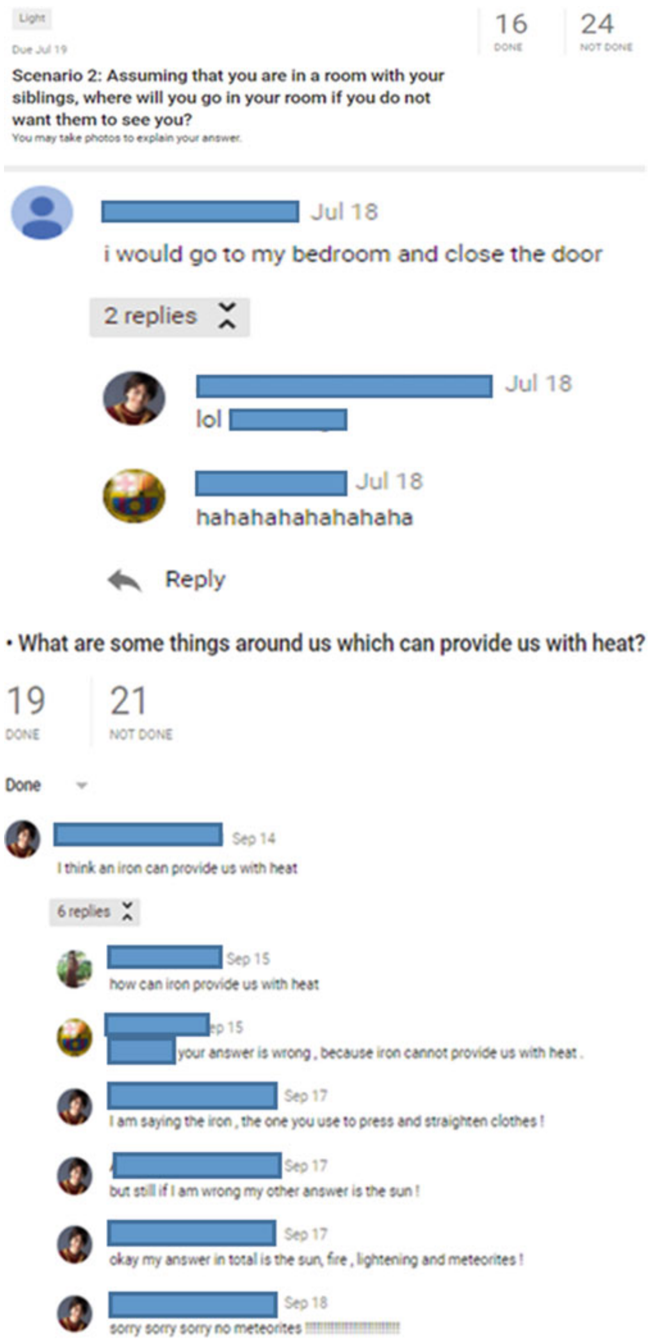

Fig. 3 Students' easy-going and yet potentially constructivist peer interactions online (from class S1P417-2)

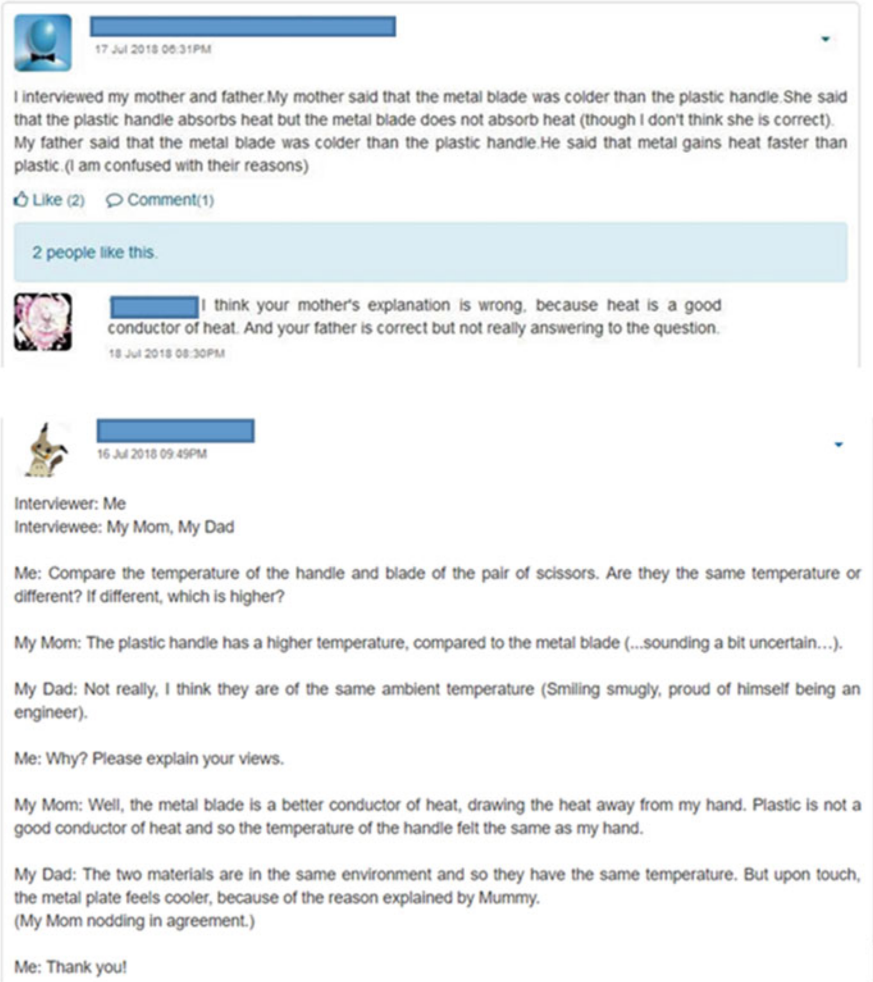

Fig. 4 Students conducted interviews at home pertaining to the temperatures of handle and blade of a pair of scissors, and scrutinised their interviewees' views (from S3P418-2)

T31: Yes, we call this triangulate. Triangle has got three sides, right? That means you don't only look at one. Look at three sites to make sure that all the different points of view are talking about the same thing, so Student3 is very clear in saying that if you go to one website that tells you that saliva is not a digestive juice. ... Then if the other three, or if you really want to be very, very sure, five websites say the same thing, very likely to be accurate. (The lesson "human digestive system" in class S3P417-1)

Personalised Learning

We positioned this as an optional design principle in response to participating teachers' feedback, given the systemic priority of covering the national curriculum-imposed learning objectives and limited time available to facilitate differentiated learning or interest-driven learning. The teachers appreciated the rationale behind this principle and had been attempting to give students greater freedom in deciding what and how to learn whenever the circumstances allowed, which may constitute a small degree of self-directed learning. An excerpt of an in-class teacher-student dialogue demonstrates this (note: Student1 and Student2 belonged to the same group),

T21:	I would like you to write down what are you trying ...
Student1:	To find out if the material takes the least time to melt the popsicle.
T21:	Okay, the material. So, you can write the aim of the experiment. Then, think about what are some of the materials you will need for making it? *(afterward, at group presentations)*
Student1:	The aim is to choose a different type of bag is good for ice popsicles to not to melt for at least 15 minutes.
T21:	Okay. The aim is different. They have a time there. At least 15 minutes. So what are the instruments, what other additional instruments that you guys will need? *(i.e., the teacher allowed the student group to set their own experiment goal and helped them to accomplish that)*
Student2:	Instruments are thermometer, different type of bags, like metal, leather and foam. Ice popsicles, salt, Ziplock bag and plastic bottles.
T:	Student2, what kind of instrument do they need? What are the variables that you have kept the same? Beside what they have said earlier?
Sttudent1:	Room temperature
T21:	So that is environment, right?
Student1:	Size of the bag. Volume of ice popsicle.
T21:	Wait wait, they have one more, they have volume of popsicle. Okay we also need that to be the same. What else?
Student1:	Temperature of ice popsicle. The environment. Amount of salt.
T:	Amount of salt. Why salt?
Student2:	The salt can keep the ice don't melt so fast. *(The dialogue continued where T21's subsequent questioning made the students realise that salt was not needed in the experiment given the objective they had set.)* (The lesson on "heat" at S2P417-1, July 2017)

A teacher's observation may be an indication of an increased level of self-directed learning among her students,

> To facilitate independent learning, let's say in online discussion, if their friends stated a wrong fact, they would research why the friend was wrong and gave a correct concept to them. In the past, they wouldn't do it, because they wouldn't come prepared before lessons to answer the questions. (Teacher T12, post-interview)

Teachers' Reflections of Teaching Practices

As reflected in Table 1, ten teachers were involved in the study. The teachers' experiences in teaching the science subject in Singapore primary schools ranged between 2 and 17 years. Among them, T11, T23, T31 and T33 were Science Heads of Department (HODs) of their respective schools in the years of their study participation, while T21 was the ICT HOD of his school. According to our pre-intervention interviews, all teachers had been adept in practicing the national curriculum-aligned inquiry learning underpinned by the 5E model of science instruction (Bybee, 2002), which include five phases of learning process, namely, Engage, Explore, Explain, Elaborate and Evaluate. Nevertheless, prior to the study, all of them were predominantly and habitually facilitating in-class student learning activities with additional homework as learning reinforcement. They hardly employed ICT or potential learning opportunities offered by the out-of-class, authentic environment to complement their teaching. A special case was T11 who reported that she had been practicing flipped learning in delivering selected lesson topics.

We qualitatively coded the transcripts of teacher interviews and classroom lessons, again around the five design principles of C^2FIP. The intention is to investigate teachers' implementations of and reflections on these salient features of seamless learning. The key findings are presented as follows.

Connectivity of Learning Activities across Contexts

All but one (T34) teachers viewed this most salient concept of seamless learning positively. Some of them perceived the learning approach as a vehicle to overcome the limited class time.

> Seamless learning is something that the students get to experience and understand the concept based on what they have discovered outside the classroom, with the help of technology. (T32, pre-interview)

> For seamless learning ... we are really trying to think of the way to make learning happen in the informal situation whereby something that is not intentionally build upon in class ... we really try to engage our learners in different contexts, different environments, I think it will bring out learning more, rather than to say that every time we run into time constraint in school whereby everything is so rush. That is what I am hoping to achieve by seamless learning. (T21, post-interview)

Other teachers have however raised the caveats of implementing such lessons. While the accessibility of ICT at home (despite a high percentage of students having that, there are always a few underprivileged ones around) has been a commonly known issue which teachers could find ways to work around, two teachers cited the parental support factor in operationalising such learning journeys that foreground connectivity,

> For those lessons we tried out, I really needed them to do the pre-lesson activities before the class sessions. It really depended on whether the parents were actively involved in such activities ... some parents who cared enough would make sure their kids do, and feedback to me. For middle ability classes, the family is an important factor. (T11, post-interview)

> ... a lot of them *(the students)* will definitely like to go to YouTube, and like to Google, because they are digital natives. But I feel that it could also struggle with their parents... I guess it was the parents who restricted the usage of the phones, because the parents have not seen the beauty, and say, 'I don't want to give you so long to surf.' ... Maybe next year when we start again, it is useful to communicate to parents that, 'we are on this project where your child will...' If we have a meet-the-parents session at the right of the beginning, that could be a possibility. (T21, post-interview)

Socio-Constructivist Inquiry Learning/Cross-Contextual Formative Assessment

The two design principles are combined in the discussion here because they are often implemented hand-in-hand. The key concept of the former is a hybridisation of "social", "constructivist" and "inquiry" learning. In the participating teachers' SSIL lesson designs, inquiry learning usually takes place at in-class small-group experiments with well-defined procedures. Yet socio-constructivist learning is a broader umbrella term that covers not only such experiments but also other online activities that require students to individually collect and interpret data in authentic settings or on the web, which constitute rich resources for subsequent knowledge co-construction. Such individual-to-social trajectory can be regarded as a trajectory of cross-contextual formative assessment. The participating teachers' relevant comments have focused more on socio-constructivist learning in a general sense,

> With seamless learning, they *(students)* are able to do research; otherwise they will have to go back to books and encyclopedia. Seamless learning helps to facilitate discussion. Deeper learning is not sufficient if just reading but do not provide comments. (T23, post-interview)

A teacher explained why online discussion activities were valuable even if not all the students participated in out-of-school online discussion,

> ... I did get maybe 30-40% responses. From what they responded, I could screenshot and use it for classroom discussion. To me, it didn't matter how many people responded; just needed to capture important points and share with the class. I could use it as a teaching point. It was very clear to some of the students ... I thought that one was actually a form of assessment because they checked on their own understanding. (T11, post-interview)

The following excerpt of classroom teacher-student discourse in the topic of light illustrates this. The pre-lesson home-based assignment required the students to share and explain ideas of hiding in the ways that their family members could not see them, with photos taken as illustrations. Then she initiated in-class discussion accordingly.

T11: *(Showing Student A's post on a PowerPoint slide)* Where do you go so that your sibling cannot see you?
Student A: Hide under my bed.
T11: Why under the bed?
Student A: Because play hide and seek want to find new place.
Student B: Dark places in my room.
T11: Which part of your room is dark?
Student C: Behind the curtain, carboard.
T11: Most of you are correct saying under the bed, behind the door, under the blanket *(according to their posts)*. Most of your ideas are hiding behind opaque objects. What do you recall about opaque during P3?
(Many students raised their hands and T11 invited Student D to answer)
Student D: Does not allow light to pass through. (The lesson on "light and shadow" in S1-P417-1, July 2017)

The teachers from school S3 moved one step further by formulating a principle to select suitable topics in the science curriculum to design seamless lessons. When being asked about their priority in implementing seamless science lessons, T31 elaborated,

> We want them *(the students)* to co-construct ideas. Why we chose these topics – heat and materials? Because these are the two topics that we find it very difficult to 'limiting' if teacher would have to give examples. With seamless learning their examples of applications will be more ... because they go beyond classroom, beyond the teachers, ... they search from real-life themselves, and they get from their classmates. So they get more examples that will help. (T31, post-interview)

Leveraging Resources in Informal Settings

Teacher T21 shared his reflection on the value of leveraging resources in informal settings to advance students' learning. This is a means to foster their "eyes of science" in their daily lives. First, when being asked to compare inquiry learning and seamless learning, he posited,

> I don't think I can compare. They are different things. Inquiry to me is I am giving the children the chance to talk, I am giving the children the opportunity to explore ... *(For example,)* today I am going to teach about heat traveling from a hotter region to a colder region; so the children can think (*imagine*) that heat will always travel from a hotter to a colder region. But I think inquiry is getting them to explore. Did they observe that heat really travel from hotter to colder region? What was the observation that they made? What kind of measurement can they make to prove that what they have said is true? ... In terms of seamless, I am just extending it to some other contexts whereby even be as simple as I may not need to conduct the lesson in my class. I would ask them to observe things that they have seen in their daily lives and they can really connect with. So I think it is sort of like complementing one another. (T21, post-interview)

He further reflected,

> When I taught the same topic in other schools, I found that the children would always have only remembered what was in the textbook, but a lower application in real life. Now we brought in the cake, the oven ... In the midst of doing all these, we are actually exposing them to see a lot of things available in their daily lives. Maybe they have seen them but not really thought or discussed about it. ... In the upcoming Summative Assessment 2 (i.e., the year-end school examination in Singapore schools), when it comes to applications, we must really look at these students who went through this (*SSIL lessons*), whether is it more evident that they are able to apply, as compared to a class which has not gone through it. (T21, post-interview)

Personalised Learning

As explicated before, it was virtually impossible for the teachers to facilitate "genuine" personalised learning among the students. Yet with this optional design principle in mind, the teachers had been consciously infusing activities with greater flexibility (in terms of how to execute them) or encouraging self-directed explorations and sharing. One teacher recounted her students' initiative of sharing and discussion on a topic not covered by SSIL, but perhaps inspired by the previous SSIL lessons they went through,

> The students initiated to send photos of caterpillar becoming a butterfly. We then started to count how many weeks it has been through and explained its survival rate. I linked this to the life cycle and built on this by asking whose butterfly is at the pupa stage. Then the students identified that this is a pupa and it is in silver, not brown; different butterflies in a different pupa colours, etc. (T32, post-interview)

Indeed, in general sense, self-directed learning does not equal personalised learning. However, the practice of self-directed learning by the students may elicit or promote personalised learning, particularly with the teacher's intervention to help an individual student optimise such a self-determined learning effort for the latter's learning need.

Yet the teachers still observed various relevant challenges faced by the students,

> Depends on the class. Some classes don't have the knowledge to go back and do self-directed learning. The self-directed ones are more willing to go on to the platforms to do self-directed learning before class. With this, we can tap on their prior knowledge. (T23, post-interview)

> For the experiment in Light, they'll experiment on how they will hide in such a way that their family members can't see them. I think it has to do with the crafting of the activities. Yesterday you showed us a sample lesson plan. It's more inquiry based. They *(the students)* have to design their own protocol. I don't think my students have achieved that level yet, I can see it only in my higher-level students. (T12, post-interview)

Implications and Discussion

Implications on Further Diffusion of Seamless Hybrid Science Learning

Apart from tangible deliverables such as new seamless science lesson plans, an important contribution of the SSIL project is a better understanding on what it takes to “bridge” the school-facilitated seamless science learning practice from 1:1 to the division of labour model. The outcomes of our study show both promises and challenges.

Despite an earlier doubt that the absence of learners’ personal devices would undermine the potential effectiveness of seamless learning, SSIL’s “division of labour” lesson plans were in general adhering to the first four design principles of C^2FIP (except with low degrees of personalised learning), managed to increase students’ engagement level (because of the novelty in the learning activities and the use of ICT) and resulted in significant learning gains in the second year of implementations (in S2 and S3). The teachers have also acknowledged the value of SSIL lessons upon the end of the study, as they observed their students’ positive changes in various aspects.

Student cohorts of S2-2018 and S3-2018 who all underwent the lessons of the second design iterations scored significantly higher in their post-tests as compared to the corresponding pre-tests. Thus, the study provides evidence support that seamless learning based on the “division of labour” model is not only a feasible but a good compromising technological model for 1:1 in seamless learning, given the current conditions in typical primary schools in Singapore, and in many other countries.

Yet, challenges are inevitable for the introduction of any innovative pedagogical model, such as not all students participated in the out-of-school online activities as instructed, the lack of parental support in or overt parental regulation of ICT-mediated tasks, and the small percentage of underprivileged students who have less or no accessibility of ICT at home. To tackle these issues, the teachers have put in measures to work around the constraints. These are by no means perfect solutions, yet they could at least mitigate the problems.

A more profound challenge for wider diffusion of seamless science learning is related to the schools’ and teachers’ willingness and readiness to implement longer term and more frequent seamless lessons. Indeed, seamless curriculum is more than redesigning lessons and putting technological resources in place. Seamless learning should be regarded as a culture, and, as advocated by researchers in the field, the learners need to be engaged in an enculturation process to progressively transform their existing habit-of-mind in learning.

Another key implication pertaining to teachers’ growth lies in some participating teachers’ reflections on how their involvement in seamless lesson design and implementation had impacted their own teaching styles which might potentially spill over to their routine teaching (even when they do not facilitate seamless learning), such as “talking less, letting students talk more”, inclination to use ICT for lessons, and engagement with parents. Their in-depth exposure to advanced pedagogical models which is novel to them may constitute opportunities for them to think out of box, to reflect upon and challenge their extant beliefs about their practices of teaching – in how they interact with their students, assess their students, be more sensitive to their students' needs, and be more adaptive in both their lesson designs and actual teaching, etc.

Implementation of the novel pedagogical model in the participating teachers' classes might also draw students' talents or competencies, particularly relating to soft skills or ICT literacy, which are otherwise not manifested in regular lessons and standard class assessments. The teachers would then rethink their previous assumptions on their students' abilities and therefore adapt their lesson design or enactment accordingly. Thus, whether or not they continue to implement the pedagogical model in a sustained manner beyond the study, their involvement in the study is valuable to them.

Conclusion

This project addressed the adaptation of the SSIL model to fit the conditions of three schools in which the constraint of the requirement of one tablet per student was removed. This work demonstrates that through a process of scaffolding by the researchers, primary science teachers can be empowered to design good SSIL lessons that adhere to techno-pedagogical design principles. Research data analysis showed evidence of student learning as well as teacher growth in designing and implementing SSIL lessons (Voon et al., 2019, 2020). The project findings have led us to useable knowledge in terms of a deeper understanding of a hybrid learning model that is built on the seamless science learning, and how to bridge such practices from the use of 1:1 technologies to a division of labour model.

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