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"Bring Your Own Device (BYOD)" for seamless science inquiry in a primary school

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A B S T R A C T

This paper reports a one-year study on the project of "Bring Your Own Device (BYOD) for seamless science inquiry" in a primary school in Hong Kong. BYOD in this study refers to "the technology model where students bring a personally owned mobile device with various apps and embedded features to use anywhere, anytime for the purpose of learning". The study aims at investigating (a) what advancement of content knowledge students made in their science inquiry in a seamless learning environment supported by their own mobile device; (b) how the students advanced their content knowledge in science inquiry; and (c) what students' perception is regarding their learning experience supported by their own mobile devices. The topic of inquiry was "The Anatomy of Fish". Data collection included pre- and post-domain tests, self-reported questionnaire, student artifacts, class observations and field notes. Content analysis and a student artifact tracing approach were adopted in the data analysis to examine and trace students' knowledge advancement. The research findings show that the students advanced their understanding of the anatomy of fish well beyond what was available in the textbook and they developed positive attitude toward seamless science inquiry supported by their own mobile devices.

1. Introduction

In the digital age, mobile technologies have become embedded and ubiquitous in students' lives. It is reported that by the end of 2011, there were 6 billion mobile subscriptions globally (International Telecommunication Union, 2012). Parallel to that, studies on "mobile-assisted seamless learning" which refers to seamless learning mediated by a 1:1 setting, have boomed (Wong & Looi, 2011). In general, mobile-assisted seamless learning research has focused on students provided with a uniform type of device (e.g., Looi et al., 2010; Song, Wong, & Looi, 2012). However, nowadays more and more learners bring their own mobile devices wherever they go for their learning and communication needs. How school students perceive and use these various types of personally owned devices to support their science inquiry in a seamless learning environment has rarely been explored.

In addition, despite the fact that inquiry-based learning in science supported by technologies has been promoted for decades and has apparently yielded intended outcomes and developed positive attitude (Looi et al., 2011), it is reported that science inquiry practices are challenging tasks for students, especially for young learners due to various issues (Krajcik, Blumenfeld, Marx, & Soloway, 2000).

Further, with seamless learning environments on the rise, tracing the learning process poses a challenge for understanding students' knowledge advancement due to the distributed and sparse nature of interactions through and over mobile devices (Looi, Wong, & Song, 2012).

In the light of the above issues, this study is aimed at investigating what advancement of content knowledge students made in their science inquiry in a seamless learning environment supported by their own mobile device, how students advance their content knowledge, and what students' perception of their seamless science inquiry experiences is. The rest of the paper introduces the relevant literature first, then describes the research design. Finally it presents the results, followed by discussion and conclusion.

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2. Literature

2.1. Bring Your Own Device (BYOD) for mobile-assisted seamless learning

According to Wong and Looi (2011), one aspect of mobile-assisted seamless learning concerns the "combined use of multiple device types" (p. 2367). In recent years, more and more studies have attempted to investigate how mobile learning can be leveraged to increase student engagement and teacher productivity through the Bring Your Own Device (BYOD) model (e.g., Project Tomorrow, 2012; Rinehart, 2012). According to Alberta Education (2012), BYOD refers to "technology models where students bring a personally owned device to school for the purpose of learning". MacGibbon (2012) maintains that the concept of BYOD is simple: if a student already has a preferred mobile device at home, it is practical to bring it to school rather than duplicate cost and waste learning time to navigate a school-issued device. BYOD is considered a technology model for learning in the 21st Century which is "Mobile Devices + Social Media = Personalized Learning" (Project Tomorrow, 2012). Although BYOD is generally considered to help promote better outcomes via a more personalized learning and an enhanced engagement between home, school and other spaces, how *BYOD* works for inquiry-based pedagogical practices in authentic learning environment has rarely been studied.

Moreover, a recent study on "ownership versus on-campus use of mobile IT devices by university students" reported that students' high mobile device ownership rates by no means imply their preference or support for university BYOD strategies (Kobus, Rietveld, & van Ommeren, 2013). Students' enthusiasm for using BYOD for learning anytime, anywhere might be reduced as time goes on (Rinehart, 2012). It is important to understand what primary school students' perception of BYOD for seamless inquiry-based learning in science. The use of the technology alone would be insufficient to foster learning without the adoption of appropriate pedagogies (Ertmer & Ottenbreit-Leftwich, 2013).

2.2. Guided science inquiry for young learners

Inquiry-based learning has been advocated in science pedagogical practices (e.g., Krajcik et al., 2000; Lakkala, Lallimo, & Hakkarainen, 2005). It can be defined as a process of posing questions, gathering and analyzing data, and constructing evidence-based explanations and arguments by collaboratively engaging in investigations to advance knowledge and develop higher-order thinking skills (Hakkarainen, 2003; Sandoval & Millwood, 2005). Teachers are expected to play a facilitating role to help learners to brainstorm ideas, generate questions for exploration, plan and carry out investigations, collect data, gather information, and apply the information to analyze and interpret the data (Hakkarainen, Lipponen, & Jarvela, 2002). However, research findings show that students lack inquiry skills and need considerable support to become knowledgeable about content, competent in using inquiry skills, proficient at using technological tools, productive in collaborative work and capable of articulation and reflection (Krajcik et al., 2000; Lakkala et al., 2005). To guide young learners in science inquiry, it is suggested that guided inquiry be adopted in the pedagogical design (Hakkarainen, 2003).

2.3. Mobile assisted seamless science inquiry

Mobile technologies have been widely adopted in inquiry pedagogical designs to support students' science inquiry and develop students' critical thinking skills in a seamless learning environment (e.g., Jones, Scanlon, & Clough, 2013; Looi et al., 2011; Shih, Chuang, & Hwang, 2010). Mulholland et al. (2012) reported a mobile software toolkit – nQuire developed to support students' inquiry in four aspects: regulatory processes (e.g. planning monitoring and evaluating progress with inquiry); transformative processes (e.g. sensemaking and articulation); collaboration and mobility. Findings of the study on nQuire supported science inquiry indicate that the mobile software toolkit could help enhance students' learning control, collaboration and mobility across a range of contexts (Jones et al., 2013). Shih et al. (2010) reported a study on inquiry-based learning practices across digital and physical environments supported by mobile technologies. The results show that there was significant improvement in students' cognitive learning achievements via a more customized learning pace and process, and by receiving scaffolding catered for individual needs. To do science inquiry seamlessly, students need to search and share information, collect and create science data, discuss and coordinate with peers without time and place constraints. Mobile technologies provide a host of affordances (i.e., possibilities for action, Barab & Roth, 2006) to help achieve these goals (Looi et al., 2011; Song, 2011). The affordances of mobile technologies include tools for multimedia access, multimedia collection, communication, representation, information sharing, knowledge construction, connectivity, reference and analysis (e.g., Churchill & Churchill, 2008; Song, 2011). Effective use of these affordances in seamless science inquiry is conductive to students' knowledge advancement.

2.4. Methodological issues in mobile-assisted seamless science inquiry

In seamless science inquiry supported by mobile devices, due to the limited screen size, and the mobile nature of the activities, learning can occur in constantly changing contexts such as home, school and other spaces (Looi et al., 2012). To capture the seamless science inquiry process is a demanding task (Rogers & Price, 2008). We need to examine holistically and "re-construct" learning occurring in different contexts in order to track learners' inquiry learning processes and outcomes in continually moving and re-constructed contexts in a seamless learning environment (Looi et al., 2012).

3. This study

3.1. Research questions

This study aimed at investigating students' content knowledge advancement and perception of learning experiences in a seamless learning environment supported by BOYD. The research questions were:

(a) What advancement of content knowledge did students make in science inquiry in a seamless learning environment supported by BYOD?
(b) How did students advance their content knowledge in science inquiry in a seamless learning environment supported by BYOD?
(c) What was students' perception of seamless science inquiry experiences supported by BYOD?

3.2. Context

The study took place in the one-year project of "Bring Your Own Device (BYOD) for seamless science inquiry" in a class of Grade Six with twenty-eight students in a primary school in Hong Kong, adopting a mixed research method (Creswell, 2008). The study involved five science units with twelve topics. For this paper, the topic "The Anatomy of Fish" in the unit "Biodiversity" was chosen to examine the students' inquiry.

3.3. BYOD and mobile apps

"BYOD" in this study refers to "the technology model where students bring a personally owned mobile device with various apps and embedded features to use anywhere, anytime for the purpose of learning". Of the twenty-eight students, twenty-four used mobile devices brought by them from home. These were ten iPads, eleven Android tablets or smartphones, two iPhones and one iPod. Four students did not own a device, so the school lent them iPads to use. Students could use the mobile devices to take photos, videos or record audio files for their own learning needs. They could also access the Internet via WiFi in school.

Three mobile apps were used in the science inquiry, namely Edmodo, Evernote and Skitch. Edmodo – a free social network platform – was used for students to communicate, share information and work, submit assignments, and coordinate learning activities seamlessly. Evernote is a suite of free software and services designed for note-taking and archiving (refer to http://en.wikipedia.org/wiki/Evernote for details). Students used Evernote to record their learning journeys, make reflections and share with peers. Skitch – a mobile app – was also recommended to the students for annotating images (refer to https://play.google.com/store/apps/details?id=com.evernote.skitch for details).

3.4. Inquiry-based learning pedagogical design in primary science

In the pedagogical design, an inquiry-based learning model was adopted premised on previous research (e.g., Hakkarainen, 2003; Krajcik et al., 2000). The model consists of six elements, namely: (a) "engage" in topics and questions of inquiry; (b) "explore" the methods and processes of inquiry; (c) "observe" the phenomena in the experiment; (d) "explain" the analyses and outcomes of inquiry; (e) "reflect" the processes and outcomes of inquiry; and (f) "share" the findings and reflections. The process is cyclic and progressive, but not linear, and may not involve all the components in each learning cycle. The model is shown in Fig. 1. The learning activities were carried out in a seamless learning environment across class, home, school lab and online learning spaces.

Before exploring the anatomy of fish, students had the prior knowledge of how to classify insects, fish, bird, mammals and reptiles based on their characteristics. The topic of "The Anatomy of Fish" was designed to make students understand in a more advanced level about the biodiversity in terms of learning to distinguish different classifications and anatomy structures from the same type of an animal – fish. To facilitate students' inquiry, four types of genuine fish were prepared by the teacher for students to investigate two questions: (1) why are the four kinds of fish called fish (based on the anatomy of fish)? and (2) what have you learned? Detailed seamless learning activities for the inquiry are presented in Table 1.

3.5. Participants

The twenty-eight students were divided randomly into seven groups of four students. This paper chose to focus on one group as an example to trace the students' inquiry process. The group has four members, two boys and two girls, given pseudonyms of Ran (boy), Tin (boy), Ling (girl) and Nini (girl). Tin and Nini used their own iPads, Ling used her own smartphone, and Ran used an iPad borrowed from the school. The teacher had around eight years of work experience and had participated in the professional development of innovations using the inquiry-based approach. In the students' science inquiry process, the teacher acted as a facilitator to guide the students' inquiry skills, and encouraged the students to use the mobile apps of Evernote and Skitch, and Edmodo to facilitate their inquiry process.

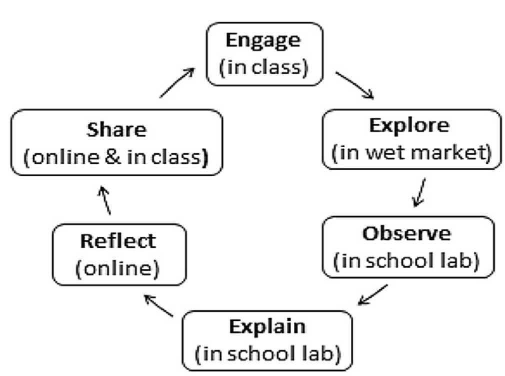

Fig. 1. Seamless inquiry-based learning model in primary science.

Table 1
The seamless inquiry-based learning activities on "The Anatomy of Fish".

Activities (As)	Description
A 1 Engage (in class)	Engage: Access Hong Kong marine fish database online (http://www.hk-fish.net/chi/database/feature/feature.htm)
A 2 Explore (in wet markets & at home)	Students search and share online information about fish on Edmodo at home, and explore a few kinds of fish in the wet market, take photos, find out the names of the fish and upload them to Edmodo.
A 3 Observe (in school lab)	There are four kinds of fish prepared by the teacher for each group to observe. They need to observe and find out the scientific names of the fish and their anatomy with the help of a magnifying glass. They are encouraged to make full use of their mobile devices in the observational process.
A 4 Explain (in school lab)	Label the body parts of the fish using the mobile app – Skitch to explain the anatomy of a fish, and upload it to Evernote which is shared in Edmodo.
A 5 Reflect (online)	Reflect on the guided questions in Evernote, e.g., Q1: Why are the four kinds of fish called fish? Q2: What have you learned?
A 6 Share (online & in class)	The students upload their labeled anatomy of fish and reflections to Evernote to share; they also share their work in class for evaluation.

3.6. Data collection

To examine what advancement of content knowledge students made and how students advanced their content knowledge in science inquiry into the anatomy of fish, data collection included pre- and post-domain tests, student artifacts (postings on Edmodo, postings on Evernote, captured photos, captured recordings, captured videos, worksheets), class observations and field notes.

The pre-domain test had two main questions: pre-Question 1 (pre-Q1) "What do you know about fish?" and pre-Question 2 (pre-Q2) "Please draw a concept map to show what you know about fish." The post-domain test also had two main questions: post-Question 1 (post-Q1) "What have you learned most about fish?" and post-Question 1 (post-Q1) "Please draw a concept map to show what you have learned about fish." The students were briefed about "a concept map" which consists of three components: nodes, lines and line labels. They were also instructed to draw circles for the "nodes" and lines with arrows to show the relationship, and to label the lines. In science learning, concept maps have been used extensively as assessment tools to examine students' relevant knowledge base development and understanding of concept interrelations within science content (Van Zele, 2004).

In addition, to identify students' perceptions of seamless science inquiry experiences supported by BYOD, a self-reported questionnaire was carried out immediately after the completion of this study. The questionnaire consisted of thirteen statements in a 5-point Likert scale (from 1 strongly disagree to 5 strongly agree) with three dimensions: (a) the first contained statements measuring students' perception of learning gains in content knowledge; (b) the second focused on students' perception of experiences in advancing meta-cognitive skills; and (c) the third addressed the social and motivational dimension of students' learning experiences. Cronbach's alpha reliability coefficients ranged from 0.857 to 0.907 for the three sub-scales; all were well above the suggested criterion 0.70 (e.g., Fink & Kosecoff, 1985). Construct validity of each dimension was determined in the form of item-to-scale correlations. Mean correlations for the individual scales ranged from 0.71 to 0.82, which were also well above the minimum acceptance level of 0.30, supporting internal consistency within each set of items in the dimension (Gable, 1986).

All the data sources used for the data analysis in this study were summarized in Table 2.

3.7. Data analysis

3.7.1. Analysis of students' knowledge advancement in science

To explore students' knowledge advancement process, a focus was laid on examining how students constructed, refined, elaborated, and created artifacts both individually and collaboratively through three streams of analysis.

First, regarding individual knowledge advancement, the author adopted a summative approach to content analysis which "involves counting and comparisons, usually of keywords or content, followed by the interpretation of the underlying context" (Hsieh & Shannon, 2005, p. 1277). The whole class's pre- and post-domain answers to pre- and post-Q1 and Q2 were examined and marked by coding the students' answers and concept maps, and categorizing them into different types, then the numbers in each category were counted, and explained in underlying context to gain better understanding of the students' learning process.

Secondly, regarding group's knowledge advancement, an artifact tracing approach – trialogical approach (Hakkarainen & Paavola, 2009) was adopted to track students' progress in science inquiry, focusing on one group as an example. The trialogical approach emphasizes group collaborative development of mediating objects or artifacts rather than focusing solely on idea improvement. The development of artifacts in group learning activities was traced in order to explore how groups work together to make sense of the problem inquiry situations (Stahl, 2002), and understand how students progressively refined artifacts or further elaborated upon shared artifacts in their inquiry process (Hakkarainen & Paavola, 2009). The artifacts included concrete objects (e.g., real fish), and conceptual/knowledge artifacts (e.g., text, pictures, and drawings).

Table 2
Data sources for data analysis.

Data		(a) How do students advance their content knowledge?	(b) What is student perception?
Domain test	Pre-domain test (pre-Q1 and pre-Q2)	x	
	Post-domain test (post-Q1 and post-Q2)	x	
Student artifacts	Postings, worksheets, captured photos, recordings and videos	x	
Class observations	Class videos, observational notes	x	
Field notes		x	
A self-reported questionnaire	13 Questions		x

Finally, students' postings in Edmodo and Evernote related to the development of content knowledge about fish were coded (Merriam, 1998). Whenever necessary, field notes were used throughout the data analysis process for the purposes of triangulation.

3.7.2. Analysis of student perception of seamless science inquiry experiences

To identify students' perception of seamless science inquiry experiences supported by BYOD, questionnaire data was analyzed statistically with the help of SPSS software.

4. Results

This section presents students' knowledge advancement process and outcomes. Students' perceptions of their learning experiences are also presented. The learning outcomes regarding what advancement of content knowledge students made in their science inquiry are presented according to the results of pre- and post-domain tests of Q1 and Q2 respectively in Section 4.1. The learning process regarding how students advanced their content knowledge is presented in Section 4.2, taking a group's collaborative knowledge advancement in science learning as an example. Finally, the questionnaire results regarding student perceptions of their learning experiences are presented in Section 4.3.

4.1. What advancement of content knowledge did students make? – Results of pre- and post-domain tests

Twenty-one pre-domain test sheets and twenty-seven post-domain test sheets were collected. By pairing the pre- and post-domain tests, we obtained 20 valid pairs of students' test sheets. The results of pre- and post-Q1 and Q2 were presented as follows respectively.

4.1.1. Results of pre- and post-Q1

Table 3 shows the summarized results of pre-Q1: "What do you know about fish?" Seven categories were identified: (a) a fish lives in water, (b) a fish uses gills to breathe, (c) a fish takes various kinds of food, (d) fish is our food, (e) a fish has scales, (f) there are different varieties of fish, and (g) others including individual answers without identical contributions such as "a fish excretes in the sea".

It is noted that the 29.6% of the answers were focused on "a fish lives in water", 20% on "a fish uses gills to breathe" and 16.7% on "a fish takes various kinds of food"; the least reported category was "there are different varieties of fish" (5.6%). This indicates that the majority of the students had the prior knowledge that a fish cannot live without water, breaths with gills and takes various food. However, their reports were heterogeneous (e.g., body part, living places, food, etc.). For example student 1 reported, "I knew that a fish uses gills to breathe. It lives in the seas. If there is no water, the fish will die".

Table 4 shows the summarized results of post-Q1: "What have you learned most about fish?" Eight categories were identified: (a) learned more about the anatomy of fish, (b) learned that a fish has lateral lines, (c) learned that a fish has more body parts than expected, (d) there are more varieties of fish, (e) learned that a fish has a few fins, (f) learned that a fish has visible or invisible scales, (g) learned that a fish has teeth, and (h) others including individual answers without identical contributions such as "some fish have a big mouth, and some fish have a small mouth that even grows on the jaw".

From the students' answers for the post-Q1, it was found that the students' reports were focused more on the topic of anatomy of fish, and their description of the fish was more detailed compared to that in the pre-test. For example, student 1 reported, "I learned that some scales on a fish are visible, and some are invisible. I also learned that the fish I studied has four fins. The shapes of fish are different and they have lateral lines. Some fish have a big mouth, and some fish have a small mouth that even grows on the jaw."

4.1.2. Results of pre- and post-Q2

Tables 5 and 6 show the summarized results of pre-Q2 ("Please draw a concept map to show what you know about fish.") and post-Q2 ("Please draw a concept map to show what you have learned about fish."). Table 5 shows that seven categories of fish related concepts were identified: (a) living places, (b) food chains, (c) fish varieties, (d) body parts, (e) fish reproduction, (f) life span and (g) others; and the presented concepts in nodes, links and link labels were focused on living places (32.9%, 33.3% and 33.6%).

While Table 6 shows that six categories were identified: (a) body parts, (b) living places, (c) food chains, (d) fish varieties, (e) fish reproduction and (f) others; and the presented concepts in nodes, links and link labels were focused mainly on body parts (73.7%, 73.5% and 74.8%). This indicates that before their inquiry into the anatomy of fish, students' knowledge structure about fish tended to be "common sense" knowledge. After their inquiry into the anatomy of fish, the students developed more focused knowledge structure and gained deeper understanding of the fish anatomy.

The findings were generally in line with the pre- and post-Q1 results presented in Tables 3 and 4 where the pre-Q1 results show that the students' answers were diversified; while post-Q1 results show that the majority of their knowledge gains lay in the anatomy of fish.

Table 3
Percentage of each category mentioned by the students in pre-Q1.

No.	Categories	$n = 54$	% Of total
(a)	A fish lives in water	16	29.6
(b)	A fish uses gills to breathe	12	20.0
(c)	A fish takes various kinds of food	9	16.7
(d)	Fish is our food	4	7.4
(e)	A fish has scales	4	7.4
(f)	There are different varieties of fish	3	5.6
(g)	Others	6	11.1

Table 4
Percentage of each category mentioned by the students in pre-Q1.

No.	Categories	$n = 60$	% Of total
(a)	Learned more about the anatomy of fish	17	28.3
(b)	Learned that a fish has lateral lines	9	15.0
(c)	Learned that a fish has more body parts than expected	8	13.3
(d)	There are more varieties of fish	7	11.7
(e)	Learned that a fish has a few fins	5	8.3
(f)	Learned that a fish has visible or invisible scales	5	8.3
(g)	Learned that a fish has teeth	4	6.7
(h)	Others	5	8.3

Table 5
Pre-Q2 percentage of related concepts in nodes, links and link labels in the map.

Related concepts	Nodes		Links		Link labels	
	$n = 146$	% Of total	$n = 141$	% Of total	$n = 125$	% Of total
Living places	48	32.9	47	33.3	42	33.6
Food chains	36	24.5	35	24.8	34	27.2
Fish varieties	26	17.8	24	17.0	24	19.2
Body parts	18	12.3	17	12.1	15	12.0
Fish reproduction	5	3.4	5	3.5	3	2.4
Life span	4	2.7	4	2.8	4	3.2
Others	9	6.2	9	6.4	9	7.2

Figs. 2 and 3 are examples of pre- and post-concept maps presented by Student 1. The concepts in the nodes and link labels are translated into English. To distinguish the translated concepts in the nodes from link labels, the translated link labels were put in brackets. Student 1's pre-concept map demonstrates that before starting the inquiry learning, his understanding of fish tended to be general knowledge about fish; while after the inquiry learning, his understanding of fish centered on the fish body parts and their functions.

4.2. How did students advance their content knowledge? – Results of group's knowledge advancement on fish in science inquiry

Another way of examining the students' knowledge advancement was presented by tracking one group's development of artifacts related to fish anatomy in the six inquiry learning activities guided by the seamless inquired-based learning model.

4.2.1. Activities 1 & 2: engage and explore (in and out of class)

In the first activity, the teacher engaged the students by introducing some online information about fish in class, and then group members Ling and Tin explored the information about fish on various websites at home, and shared these on Edmodo (see Figs. 4 and 5) using their mobile devices as an information sharing tool or using computers at home; group members Ling and Tin also went to the wet market and used their mobile devices as multimedia collection and information sharing tools to take some pictures of different kinds of fish and shared them on Edmodo to get a general understanding of fish. Fig. 6 posted by Ling is an example of this. Ling also made a recording using her mobile device to describe the kinds of fish she observed in the wet market, and uploaded it to Evernote which was shared on Edmodo.

4.2.2. Activities 3 & 4: observe and explain (in school lab)

In the lab, the four group members observed four kinds of fish bought and distributed by the teacher, and each of them was responsible for finding out the scientific name and labeling the body parts of one kind of fish. They studied the fish attentively with the help of a magnifying glass, referred to the online information on Edmodo, took pictures of the fish, and labeled the body parts on the captured photo using Skitch app, and finally uploaded the labeled photo to Edmodo. In these activities, the mobile devices were used as referential, multimedia collection, connectivity and annotation tools altogether. Fig. 7 shows that in the group, three members were using an iPad and one was using a smartphone to explore the information about fish online in Edmodo. Fig. 8 shows that Ran was comparing the information recommended by group member Tin in Edmodo about the fish online with the fish he was studying while labeling the anatomy of the fish using the mobile app Skitch.

Table 6
Post-Q2 percentage of related concepts in nodes, links and link labels in the map.

Related concepts	Nodes		Links		Link labels	
	$n = 171$	% Of total	$n = 170$	% Of total	$n = 151$	% Of total
Body parts	126	73.7	125	73.5	113	74.8
Living places	16	9.4	16	9.4	14	9.3
Food chains	12	7.0	12	7.1	10	6.6
Fish varieties	9	5.3	9	5.3	6	4.0
Fish reproduction	2	1.2	2	1.2	2	1.3
Others	6	3.5	6	3.5	6	4.0

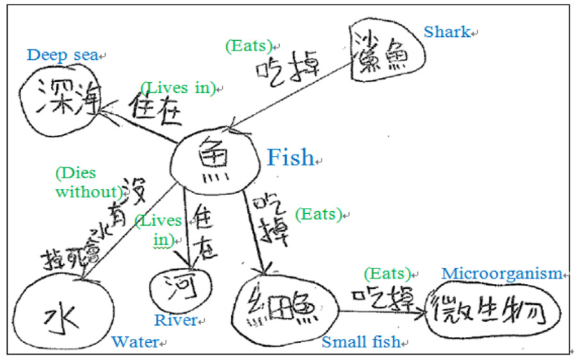

Fig. 2. Student 1 pre-concept map.

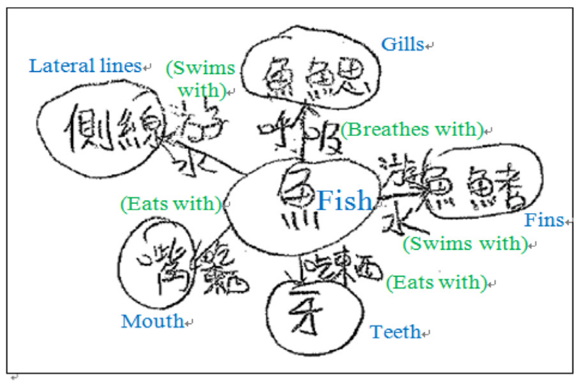

Fig. 3. Student 1 post-concept map.

Fig. 4. Website about fish shared by Ling.

4.2.3. *Activities 5 & 6: reflections in Evernote and share*

All four members posted their labeled anatomy of fish to Evernote using their mobile devices as an information connection tool. The annotated anatomy by Tin was shown in Fig. 9.

All the members wrote their reflections on Evernote using the mobile device as a knowledge construction tool except Nini. Tin reflected:

> "Today, we did an inquiry into "fish"… I divided the fish into several parts. They are: eye, pelvic fin, gill, spiny dorsal fin, anal fin, etc. The fish I studied and the other fish my group members studied all belong to fish because all of them have gills, anal fins, fins and scales. Based on these, I know that they are fish. In addition, before the experiment, I thought that fish is hard if it is not cooked; after the experiment, I learned that what I thought was wrong. Fish meat is not hard at all, but soft and elastic. From the experiment, I learned a lot of knowledge about fish, for example: anatomy, features, quality of fish meat and scales."

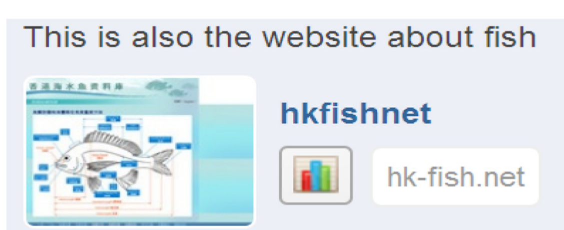

Fig. 5. Website about fish shared by Tin.

Fig. 6. Photo taken in a wet market shared by Ling.

Ran reflected that "I learned in Wednesday's experiment, different body parts of the fish, for example: lateral line, gill, pelvic fin, and spiny dorsal fin. The fish I studied is Golden Threadfin Bream". Ling reflected that "All of them are fish because they use gills to breathe and use fins to move." Only Nini failed to post any reflections. The teacher encouraged her by commenting on the labeled fish she uploaded to Edmodo, "Great! Well done!! Can you find the name of this fish?" Encouraged by the teacher, Nini worked hard to find out the name and detailed information about the fish and posted it to Edmodo.

The group of students investigated both collaboratively and individually the anatomy of fish. The process was traced and documented, and is shown graphically in Fig. 10. Due to space limitations, only a small number of the students' mediating and conceptual artifacts can be shown in the paper.

4.3. What was students' perception of seamless science inquiry experiences supported by BYOD? – Results of student self-reflected report on perceptions of seamless science inquiry supported by BYOD

The questionnaire results of students' perceptions of seamless inquiry experiences supported by BYOD are presented in Table 7.

Table 7 shows the results of student perceptions of seamless science inquiry experiences supported by BYOD. The mean values of students' responses to their perceptions of the experiences (calculated against the 5-point Likert scale) were all above 4.0 in all three dimensions. The results suggest that the students perceived overall learning experiences positively.

Fig. 7. Mobile devices used by the group members.

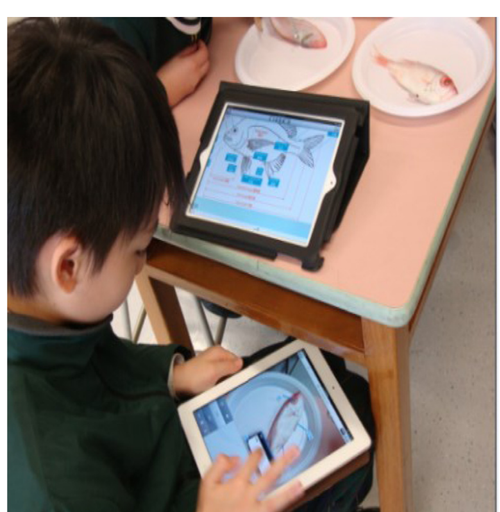

Fig. 8. Ran – working on the fish.

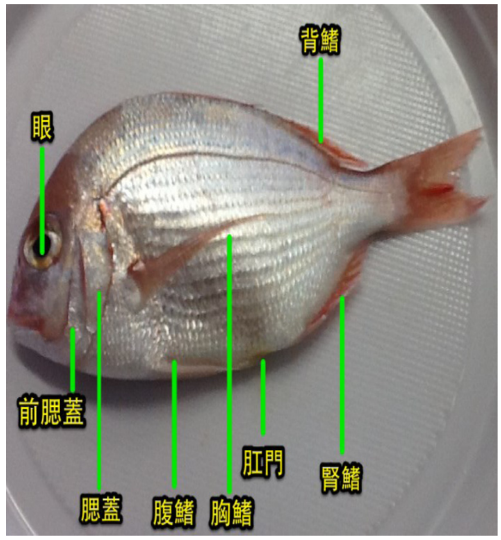

Fig. 9. A fish labeled by Tin.

5. Discussion

This study investigated students' science knowledge advancement using pre- and post-domain tests, each consisting of two questions. The pre-domain test results show that students' pre-domain test answers and mapped concepts (nodes, links and link labels) were not focused on the anatomy of fish. After the inquiry in the lab supported by mobile devices was completed, the post-domain test answers indicate that the students' learning was focused more on the anatomy of fish and the functions of the body parts. Their presented concepts shown in their post-domain concept maps also demonstrated more focused knowledge structure of the anatomy of fish. This suggests that students' understanding of fish anatomy was enhanced as a result of their BYOD for seamless science inquiry. Further, by tracing one group's inquiry process, the author was able to follow and analyze how the group members developed their artifacts relating to the anatomy of fish. Their science inquiry was mediated by the artifacts/objects developed earlier both collaboratively and individually supported by their mobile devices across different learning spaces of wet market, home and school lab.

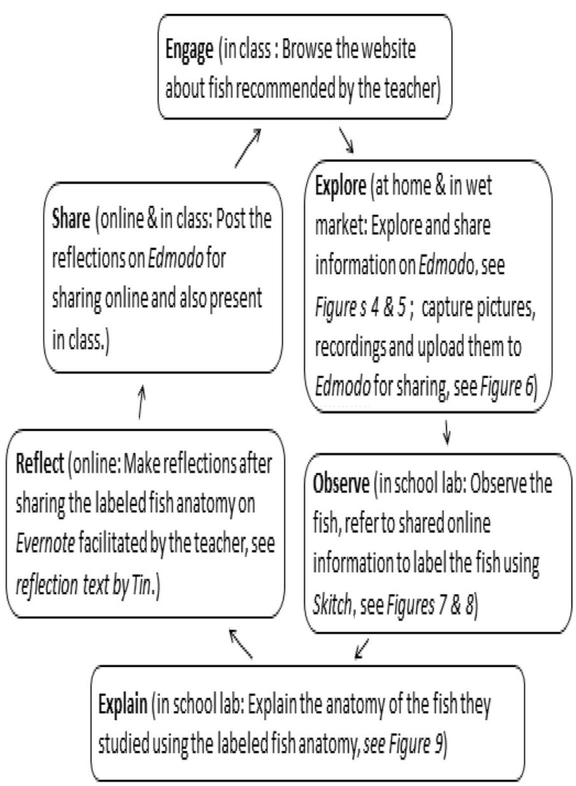

Fig. 10. Tracing the group's knowledge advancement on "The Anatomy of Fish".

Table 7
Self-reported questionnaire results on student perception of seamless science inquiry supported by BYOD.

Dimensions and questions	Mean	SD
Content knowledge	**4.25**	**0.61**
-Use of BYOD helps me relate better the science content knowledge learned in the classroom to the things in my daily life.	4.16	0.62
-I can understand better the content knowledge learned in the classroom supported by BYOD.	4.28	0.61
-Use of BYOD helps deepen my understanding of science knowledge.	4.32	0.75
Meta-cognitive skills	**4.21**	**0.67**
-Use of BYOD allows me to do science inquiry anytime, anywhere.	4.20	0.58
-Use of BYOD allows me to do science inquiry beyond the classroom.	4.16	0.90
-I could explain/present my/our group research results better supported by BYOD.	4.28	0.79
-Use of BYOD makes me formed a habit of raising questions in science inquiry.	4.24	0.83
-Use of BYOD helps me make more reflections in science inquiry.	4.12	0.93
-I could try different ways to do science inquiry supported by BYOD.	4.24	0.78
Social & motivational	**4.32**	**0.69**
-I am more motivated to do science inquiry supported by BYOD.	4.36	0.95
-Use of BYOD in the science inquiry can help improve collaborative learning.	4.28	0.74
-My teacher supports me in using BYOD to enhance my learning.	4.40	0.71
-My parents support me in using BYOD to enhance my learning.	4.24	0.88

The findings of the study indicate that integrating the BYOD technology model into guided inquiry-based pedagogical design and implementation in a seamless environment will help young learners' advance their content knowledge. By making use of varied affordances of mobile devices, students could create artifacts to share on the social network Edmodo and Evernote, and collect data about their own observations of fish in the wet market and the school lab, students acquired knowledge about fish way beyond what was available in the textbook. In the course of their science inquiry, students had a sense of ownership and control over their own learning which was lacking in previous mobile learning research where they had to borrow the mobile device from school (Corlett, Sharples, Bull, & Chan, 2005; Jones et al., 2013). It is found that BYOD can facilitate students' science inquiry by enabling them to access and share artifacts online anytime, anywhere, which cannot be easily achieved using desktop computers. In addition, BYOD can enable students to capture "just-in-time" photos, and audio and video files, and to upload these files to Edmodo and Evernote for instant sharing. It can also allow students to edit captured photos for specific learning needs without time and space constraints (e.g., labeling the captured fish photo in the school lab). These can greatly enhance the flexibility, mobility and interactivity of learning at comparatively inexpensive cost (Wu & Zhang, 2010) and foster students' personalized learning (Song et al., 2012).

The results of the study reveal that the students held very positive attitudes toward science inquiry supported by BYOD. This suggests that the students were very much engaged in the inquiry process. The positive attitude did not simply result from the novelty effect (Liu, Liao, & Pratt, 2009) of BYOD, instead, it was the authentic seamless inquiry-based learning activities supported by BYOD that motivated them to invest sustained effort in achieving their learning goals. The technology model – BYOD alone could not be the full explanation for helping students learn (Ertmer & Ottenbreit-Leftwich, 2013; Kobus et al., 2013). Rather, it is its combination with the guided inquiry-based learning pedagogy that contributed to the students' inquiry process and fulfilling their ultimate learning goals. Just as Ertmer and Ottenbreit-Leftwich (2013) suggest, it is time that we shifted our focus from technology integration per se, to promoting technology-enabled learning.

The results of the study also show that using a trialogical approach (Hakkarainen & Paavola, 2009) to trace the students' individual and group inquiry in multiple spaces can help make the learning process and outcome visible (Stahl, 2002). The visible conceptual artifacts in the form of pictures, text, videos and recordings documented the students' learning process and mediated their learning progressively. Interestingly, students' science inquiry skills were also improved in tandem with their knowledge advancement. The development of student's inquiry-based skills will be addressed in later writings.

The study was not without limitations. It is noted that the number of participating students was small, which poses a challenge against the statistical results of the analysis. In addition, some of the issues of BYOD-supported inquire-based learning need to be addressed, such as ethical issues for students who do not own a mobile device, physical and psychological harms caused by over use of the mobile devices and so on.

6. Conclusion and implications

This paper reports a one-year case study on the project of "Bringing Your Own Device (BYOD) for seamless science inquiry" in a primary school in Hong Kong, choosing the topic of "The Anatomy of Fish". To understand what advancement of content knowledge students made in science inquiry in a seamless learning environment supported by their own mobile devices, the study focused on examining the pre- and post-domain test results; and to understand how students advanced their content knowledge in science inquiry, a trialogical approach was adopted to trace the development of students' content knowledge about fish using a group of students' work as an example. The research findings show that students advanced their knowledge in understanding the anatomy of fish beyond the knowledge in the textbook, taking advantages of various affordances of mobile devices. In addition, students developed a positive attitude toward using BYOD for seamless science inquiry.

The integration of BYOD technology model into inquiry-based seamless learning in this study yields three implications. Firstly, the BYOD technology model in conjunction with an inquiry-based pedagogy was shown to have a positive impact on students' knowledge advancement; this is largely different from previous studies that have focused mainly on technology integration (e.g., Kobus et al., 2013). The pedagogical design should be in tandem with the adoption of affordances of mobile technologies. Before implementing the pedagogical design in science inquiry, a list of affordances should be considered and how can these affordances be effectively used to enhance learning and teaching activities. Secondly, affordances of mobile devices in a seamless inquiry-based learning environment do not stand alone, but are functionally connected together to form "affordance networks" and are employed by students to achieve certain goals (Song, 2013). Because students' capabilities of perceiving and acting on the affordances are varied, it is crucial for educators to help students to increase their capability in perceiving the affordances and expanding the affordance networks in seamless learning environment in order to make optimal use of the mobile technologies for knowledge construction in learning science in schools. Last but not least, the trialogical approach used to trace students' domain knowledge advancement across different spaces sheds some light on the types of methods that could be used to examine seamless learning processes and outcomes.

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