The Impact of a Principle-based Pedagogical Design on Inquiry-based Learning in a Seamless Learning Environment in Hong Kong

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ABSTRACT
An inquiry-based learning pedagogy coupled with a seamless learning environment is a potential way to realise the educational goal of learner-centred learning in digital classrooms in the 21st century. An overarching research framework is proposed for preparing teachers to effectively develop pedagogical designs that are premised on theoretical principles and facilitate inquiry-based learning in a seamless learning environment. We carried out an initial study using the overarching framework. Three questions are addressed: how a principle-based pedagogical design was developed and implemented, the effect that the principle-based pedagogical design had on students’ domain knowledge gains and inquiry skills and how students advanced their domain knowledge and developed their inquiry skills. One teacher and 27 students from a local primary school were involved in the study. Both qualitative and quantitative data were collected and analysed over two weeks. Six inquiry-based learning lessons focusing on a scientific ‘rustproofing’ learning unit were conducted in a seamless learning environment, initiated in a digital classroom and extended to online discussions on a social network platform. The results reveal innovative ways of developing and implementing the pedagogical design in the rustproofing learning unit and demonstrate the pedagogical design’s positive effect on students’ domain knowledge gains and inquiry skills. In addition, how the students advanced their domain knowledge and inquiry skills were also explored and discussed.

Keywords
Inquiry-based learning, Primary school education, Principle-based pedagogical design, Seamless learning environment

Introduction
Educational reform calls for a paradigm shift to learner-centred domain knowledge learning. It is well recognised that the inquiry-based learning approach is a useful pedagogy for realising learner-centred learning (Marshall, Smart, & Horton, 2010). The inquiry-based learning process helps learners to develop inquiry skills, which are an important type of 21st century skill. The development of inquiry skills takes root during a child’s senior primary school years (Lakkala, Lallimo, & Hakkarainen, 2005). Digital classrooms are on the rise; students are connected and learn in a ‘one learner to one computer’ setting, and teachers are expected to be prepared to lead students to learner-centred learning in such classrooms as early as the primary school stage. The use of online learning platforms inside and outside digital classrooms supports resource access and peer interaction to develop students’ domain knowledge and inquiry skills (Kong & So, 2008; Lakkala et al., 2005). Incorporating the inquiry-based learning pedagogy into a seamless learning environment may thus be a potential method for realising learner-centred educational goals and driving teachers to apply and reflect on pedagogical designs. This study presents a design-based research framework for principle-based pedagogical design for inquiry-based learning in seamless learning environments. It details and reports the results of an initial study conducted using this framework in a Hong Kong primary school.

Research framework
With the goal of finding a meaningful and sustainable method of developing the teacher competence necessary to facilitate inquiry-based learning in a seamless learning environment, this research study seeks to address two issues. First, the method for developing teacher competence should be in line with the method for developing learner competence in inquiry-based learning. Second, the method for developing teacher competence should present evidence of the development of teacher competence and student learning improvement. This study adopts a principle-based approach to developing and implementing pedagogical designs for inquiry-based learning. This approach, which differs from the conventional approach that emphasises “best practices” with prescribed procedures, provides more flexible scaffolding under guiding principles. It attempts to build up teachers’ capacity to promote inquiry-based learning in a manner aligned with learners’ inquiry-based learning practice. This study also adopts a
A design-based research approach to developing and refining pedagogical designs for inquiry-based learning guided by instructional principles. It exposes teachers to the process of progressive refinement in pedagogical designs driven by principles and supported by empirical evidence. In light of these issues, we propose an overarching research framework on the use of principle-based pedagogical designs for inquiry-based learning in a seamless learning environment, as shown in Figure 1.

A design-based research method is adopted to prepare teachers to effectively develop pedagogical designs that are premised on instructional principles. Learners learn in a seamless learning environment to develop the necessary skills to practice inquiry-based learning.

Inquiry-based learning includes three approaches: structured, guided and open inquiry, listed in ascending order of the learner’s autonomy over setting investigation problems and planning problem-solving procedures (Colburn, 2000). The literature suggests that the guided inquiry approach is especially suitable for young learners, as teachers only select core issues that are worthy of a learner’s inquiry (Hakkarainen, 2003; Marshall et al., 2010; Song & Looi, 2012). According to Wong and Looi (2011), seamless learning environments provide learners with opportunities to make use of diverse resources and tools in digital formats for learning and communication, which is initiated in digital classrooms and extended to online interactions. The technological support of a seamless learning environment allows learners to conveniently share and store multimedia resources, and to easily exchange and track discussion ideas with peers during the inquiry process. During class time, learners in digital classrooms are connected, and use digital technologies in a ‘one learner to one computer’ setting (Chan, 2010; Kong, 2011). Beyond the limited class time, learners typically use learning platforms to communicate with peers online, mostly to extend discussions or to engage in deeper discussions after class.

Pedagogical design refers to the organisation plan for learning activities and the actual implementation of the plan in a learning unit (Lakkala et al., 2005). Researchers have reported that principle-based pedagogical designs are more adaptable and conducive to transforming inquiry-based learning practices (Schwarz, 2009; Song & Looi, 2012; Zhang, Hong, Morley, Scardamalia, & Teo, 2011). The principle-based approach to pedagogical design defines the core principles of learning and teaching. According to Schwarz (2009), Zhang (2010) and Zhang et al. (2011), principle-based pedagogical designs focus on guiding principles and customizable practices. Teachers are afforded the flexibility to reflectively judge and adapt classroom decisions to accommodate different learning and teaching possibilities. Based on knowledge-building and social-constructivism theories (e.g., Scardamalia, 2002; Vygotsky, 1978), a set of theoretical principles premised on 12 knowledge-building principles and progressive inquiry principles (Lakkala, Muukkonen, Paavola, & Hakkarainen, 2008; Scardamalia, 2002; Song & Looi, 2012; Zhang et al., 2011) is considered suitable for pedagogical designs for inquiry-based learning.
Teachers need support from evidence-based research to make continuous pedagogical reflections. As such, the design-based research approach is suitable for gaining new insights. Design-based research attempts to combine theory-driven design with empirical analyses of practices in real settings. It creates a path to connect interventions to outcomes through an iterative mechanism of design, evaluation and refinement (Bell, 2004; Hoadley, 2004). Teachers are provided with iterative opportunities (as shown in Figure 1) to use principle-based pedagogical designs to enhance their competence in leading inquiry-based learning in a seamless learning environment. This study details and reports the results of an initial study on design-based research that explored the effect of using the principle-based approach to pedagogical designs for science inquiry in the seamless learning environment of a Hong Kong primary school.

The initial study was conducted using the overarching framework in a learning unit on ‘rustproofing’ conducted in the school’s Primary 4 class.

**This study**

**Research context**

The study took place in the initial cycle of design-based research on principle-based pedagogical designs for inquiry-based learning that aimed to develop teacher competence and learners’ science domain knowledge and inquiry skills in a seamless learning environment at the primary level in Hong Kong. According to recent territory-wide surveys on the development of technology-enhanced education in Hong Kong (Li & Kong, 2011), local primary school teachers are typically capable of integrating technology into their daily teaching methods. Further, local primary school learners are ready to use technology for inquiry-based learning, as they demonstrate a basic information literacy competency that is important in the inquiry process. These surveys reveal that primary schools in Hong Kong have built a foundation for introducing educational innovations that integrate pedagogical designs for inquiry-based learning into technology-supported learning environments.

The study purposefully sampled a primary school in Hong Kong as its partner school. One experienced science teacher and one Primary 4 class with 27 students (15 female and 12 male) were invited from the partner school to participate. The science inquiry focused on a learning unit on rustproofing conducted in six lessons over 2 weeks for senior primary school learners. The following research questions were addressed.

1. How did the teacher develop and enact the principle-based pedagogical design?
2. What effect did the principle-based pedagogical design have in helping students to gain domain knowledge and inquiry skills in the seamless learning environment?
3. How did the students advance their domain knowledge and develop their inquiry skills?

To address these questions, our pedagogical design involved the adoption of the 5E inquiry-based learning model to guide the students’ science inquiry, and five instructional principles for pedagogical practice in a seamless learning environment supported by a social network (i.e., Edmodo). These principles are elaborated in the remainder of this section.

**5E inquiry-based learning model**

According to EDB (2008), the focus of science education is to promote students’ scientific thinking through inquiry-based learning approaches. Although open inquiry provides optimal opportunities for students’ cognitive development and scientific reasoning, teacher-guided inquiry may provide better opportunities for students to focus on the development of particular science concepts (Song & Looi, 2012). To balance the two inquiry approaches, we developed a 5E inquiry-based pedagogical model as follows: (a) “engage” in inquiry topics and questions, (b) ‘explore’ the inquiry methods and processes, (c) “explain” the inquiry analyses and outcomes, (d) “evaluate” the inquiry processes and outcomes and (e) “extend” the inquiry topics and questions. The process is cyclic and progressive but not linear, and may not involve all of the components in each learning cycle.
Five instructional principles

To explicate the processes and dynamics of science inquiry for knowledge advancement using the inquiry-based pedagogical approach, we adapted five core instructional principles from a set of progressive inquiry principles (Song & Looi, 2012) and other related research (Scardamalia, 2002; Yeo & Tan, 2010). These principles are premised on social constructivist principles, and include (a) working on real problems, (b) encouraging diverse ideas, (c) providing collaborative opportunities, (d) using authoritative sources constructively and (e) performing a formative assessment (see Table 1).

<table>
<thead>
<tr>
<th>Principles</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working on real problems</td>
<td>Setting up real-life problems rather than abstract concepts (Scardamalia, 2002; Song &amp; Looi, 2012).</td>
</tr>
<tr>
<td>Encouraging diverse ideas</td>
<td>Encouraging students to express their ideas voluntarily. There is no right or wrong answer. Every idea is valued and unique (Song &amp; Looi, 2012).</td>
</tr>
<tr>
<td>Providing collaborative opportunities</td>
<td>Emphasis on the importance of collective effort and responsibility in the learning process (Scardamalia, 2002; Song &amp; Looi, 2012).</td>
</tr>
<tr>
<td>Using authoritative sources constructively</td>
<td>The meaningful use of authoritative sources for continual science meaning-making (Yeo &amp; Tan, 2010).</td>
</tr>
<tr>
<td>Performing a formative assessment</td>
<td>Provision of peer assessment and teacher feedback concurrently in the collaborative process (Scardamalia, 2002; Song &amp; Looi, 2012).</td>
</tr>
</tbody>
</table>

Teacher principle-based understanding

Before the beginning of the study, the teacher received two 1.5-hour training sessions from two researchers. In the first session, the researchers prompted and discussed the inquiry-based learning model and five instructional principles with the teacher using PowerPoint slides. The researchers then asked the teacher to reflect and pose questions. In the second session, the teacher chose one of his lessons to elaborate how he would conduct it using instructional principles, and discussed his pedagogical design with the researchers.

Seamless learning environment supported by a social network—Edmodo

This study took place in a seamless learning environment. The teacher provided pedagogical support in implementing the 5E model and five instructional principles for inquiry-based learning. The seamless learning environment comprised digital technologies that allowed students to access learning resources and interact with peers in inquiry-based learning. Inside the digital classroom, each student was given a mobile computing device comprising a tablet PC with Internet connectivity and an embedded camera. The social network Edmodo (see Figure 2), was used as a learning communication platform to support the students’ learning at the individual, group and whole-class levels both inside and outside the classroom. Edmodo is a secure microblogging medium conducive to collaborative knowledge construction (Ma, Ko, Chu, & Song, 2012). It can be used across formal and informal learning settings, allowing students to collaborate, communicate, submit assignments and upload and download files, and teachers to share lecture notes with students, connect to useful websites, upload and download learning references for students, create online quizzes and release news and events. The platform can run on different operating systems (e.g., iOS or Android).

![Figure 2. Interface of Edmodo for the Primary 4 science class](image-url)
The learning activities organisation plan

The principle-based pedagogical design included an organisation plan of the learning activities (see Table 2) and the actual enactment of the learning unit plan on rustproofing, which comprised six lessons and activities that Primary 4 students carried out at home or between lessons over two weeks. According to the plan, the students formed six groups of four or five members each and were expected to collaboratively lead their own experimental inquiries into an “expert rustproofing design” project. Two prompts were provided on Edmodo during the experimentation process. First, the ‘Forms for Experimental Rustproofing Designs’ prompt asked students to record their inquiry plans. The students were required to fill out three design methods with hypotheses (Appendix I), and each student was required to take on a responsibility in the design. Second, the ‘Observational Forms for Rustproofing Experiments’ prompt helped students to monitor their experimental process and scaffold their reflections. The students were required to document the rustproofing process over a week and to include the observers’ names (Appendix II). Both of the Edmodo forms were linked to GoogleDocs, which allowed the students to fill them in directly.

Table 2. Learning activities organisation plan for the rustproofing learning unit

<table>
<thead>
<tr>
<th>No.</th>
<th>Aim</th>
<th>Activity</th>
<th>Means of interaction</th>
<th>Teaching and learning resources</th>
</tr>
</thead>
</table>
| Lesson 1 | To engage students on the topic of rustproofing | -Storytelling was used to make students understand why they needed to rustproof and to arouse their curiosity on how to do so.  
-Individual students were required to discover rustproofing methods and prepare to share their discoveries with group members in the next lesson. | F2F + online | LCD projector, Tablet PCs, Internet, Social network: Edmodo |
| At home | To discover rustproofing methods individually | -Individual students continued researching rustproofing methods and uploaded their findings to Edmodo to share with their peers.  
-The students posted questions to Edmodo and commented on or responded to other students’ posts. | Online learning | Desktop, laptop, iPad, iPhone, etc. Edmodo |
| Lessons 2 and 3 | To determine the three best experimental rustproofing designs in groups | -Each group member shared and explained his or her findings on the experimental rustproofing designs.  
-The three best experimental rustproofing designs were discussed and worked out by combining every member’s ideas.  
-The three best experimental designs were filled in on the ‘Forms for Experimental Rustproofing Designs’, prepared by the teacher on Edmodo to share with peers. | F2F + online | LCD projector, Tablet PC Edmodo |
| At home | To plan and prepare the material for the rustproofing experiment in the next session | -Students could post their questions to Edmodo. They could also comment on or respond to other students’ posts. | Online | Desktop, laptop, iPad, iPhone, etc. Edmodo |
| Lessons 4 and 5 | To conduct the experiment based on the proposed experimental designs in groups | -Each group conducted three rustproofing experiments by placing three iron clips into three plastic cups full of water and certain other materials.  
-The cups containing the clips and materials were placed on windowsills. | F2F + online | Three iron clips provided by the teacher for the students to conduct the experiments. Students brought the rustproofing materials from home, including the plastic cups. |
**Data collection and analysis**

To understand the effects of the principle-based pedagogical design on students’ domain knowledge of rustproofing and inquiry-based learning skills, and on how the students advanced their domain knowledge and inquiry strategies, we collected the following data.

- Data on the development and implementation of the pedagogical design, including posts on Edmodo, the learning activities organisation plan, lesson videos, group experimental design forms, group experimental observational forms, the assignment and teacher interviews and reflections.

- Data on the effects of principle-based pedagogical design on domain knowledge gains, including pre- and post-domain tests and assignments. The pre- and post-domain tests were identical and consisted of 20 multiple-choice questions and five open-ended questions on rustproofing. The assignments took the form of worksheets on rustproofing knowledge (Appendix III). The students submitted their assignment directly to Edmodo, and the teacher commented on their work directly to provide immediate feedback. The data on the effects of the principle-based pedagogical design on student inquiry skills included pre- and post-questionnaire surveys on perception changes towards inquiry learning skills before and after the inquiry-based learning approach. The questionnaire focused on students’ perceptions of inquiry learning skills, and comprised 12 items rated on a five-point Likert scale (with 5 indicating strong agreement and 1 indicating strong disagreement). The 12 items were designed to address the five inquiry skills under the 5E inquiry-based learning model, with items 1-3 addressing the “questioning” skill; items 4-5 addressing the “exploring” skill; items 8-11 addressing the “explaining” skill; items 6-7 addressing the “evaluating” skill and item 12 addressing the “extending” skill. The Cronbach’s alpha reliability scores were 0.849 and 0.902 for the pre-test and post-test, respectively, implying that the questionnaire was reliable.

- Data on how the students advanced their domain knowledge, including group experimental designs (experimental design forms on Edmodo), group experimental results/products (observational forms on Edmodo) and group artefacts (photos documenting the experimental process), and data on how the students advanced their inquiry skills, including posts on Edmodo, lesson videos, teacher and student interviews and field notes.

Table 3 shows the data sources used to investigate the three research questions.

<table>
<thead>
<tr>
<th>Data</th>
<th>Research questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre- and post-domain tests</td>
<td>*Q1 *Q2(a) *Q2(b) *Q3(a) *Q3(b)</td>
</tr>
<tr>
<td>Pre- and post-questionnaire surveys</td>
<td>x</td>
</tr>
</tbody>
</table>

Table 3. Data sources for analysis
To investigate how the teacher developed and implemented the pedagogical design, we adopted three iterative and complementary streams of content analysis: (a) a “preliminary exploratory analysis” to obtain an understanding of the data (Creswell, 2008, p. 250); (b) categorising strategies to code the inquiry skills using the five elements of the inquiry learning model (i.e., engage, explore, explain, evaluate and extend) and instructional strategies as a coding scheme and (c) contextualising strategies to identify the inquiry strategies and instructional principles implemented in the learning unit (Maxwell, 2005).

The effect of the principle-based pedagogical design on the students’ gains in domain knowledge was examined by analysing the pre- and post-domain tests using quantitative methods and SPSS software to determine the changes in students’ domain knowledge before and after the adoption of principle-based pedagogical design. The students’ assignment results were then analysed to identify content knowledge gains and problems. To investigate the effect on the students’ inquiry skills, pre- and post-questionnaire surveys were conducted to understand changes in the students’ perceptions before and after the adoption of the principle-based pedagogical design.

To scrutinise how the students’ science domain knowledge was advanced and to understand how the groups worked together to make sense of a problem inquiry situation (Stahl, 2002), we traced the students’ development of certain artefacts (Hakkarainen & Paavola, 2009), including concrete objects (e.g., experiment materials) and conceptual artefacts (e.g., text, pictures and drawings). The data analysis methods used to examine how the students advanced their inquiry skills were similar to the three iterative and complementary content analysis streams adopted to analyse the development and implementation of the pedagogical design. We also counted the numbers of students’ posts on Edmodo using a coding scheme, as a means of “counting” is necessary in qualitative data analysis in some circumstances (Miles & Humberman, 1994, p. 253). Whenever necessary, field notes were used in the data analysis process for clarification and confirmation.

Results

Development and implementation of the principle-based pedagogical design

The data analysis results on the development of the principle-based design show that the learning activities organisation plan included the five elements of the inquiry-based learning model in a seamless environment. The inquiry learning activities went from engaging students on the topic of rustproofing, to exploring rustproofing methods and making hypotheses for the experimental designs, to evaluating the experimental rustproofing designs through active experimentation and explaining and sharing the designs and finally to consolidating and extending the rustproofing knowledge to help the students to become rustproofing ‘experts’. The entire inquiry process was carried out seamlessly between classes and the students’ homes with the support of the social network platform (Edmodo).

The data analysis results on the implementation of the principle-based pedagogical design indicate that the teacher premised the rustproofing learning activities organisation plan on the five instructional principles (see Table 1). The demonstration of the five inquiry-based elements and five instructional principles in a seamless learning environment during the enactment of the rustproofing learning unit is illustrated in Table 4.
Table 4. Principle-based pedagogical implementation of inquiry-based learning in a seamless learning environment

<table>
<thead>
<tr>
<th>Implementation of the organisation plan</th>
<th>Inquiry elements</th>
<th>Instructional principles</th>
<th>Seamless learning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lesson 1</strong></td>
<td><strong>Engage</strong>: Engaging in the topic of rustproofing</td>
<td>P1</td>
<td>Class</td>
</tr>
<tr>
<td><strong>At home</strong></td>
<td><strong>Explore</strong>: Exploring rustproofing methods</td>
<td>P4</td>
<td>Home</td>
</tr>
<tr>
<td><strong>Lessons 2 and 3</strong></td>
<td><strong>Explain</strong>: Sharing and planning rustproofing experiments and making hypotheses in groups</td>
<td>P2 and P3</td>
<td>Class</td>
</tr>
<tr>
<td><strong>At home</strong></td>
<td><strong>Engage</strong>: Preparing and coordinating the rustproofing experiments</td>
<td>P1 and P3</td>
<td>Home</td>
</tr>
<tr>
<td><strong>Lessons 4 and 5</strong></td>
<td><strong>Evaluate</strong>: Evaluating the hypotheses through conducting experiments</td>
<td>P1, P3 and P5</td>
<td>Class</td>
</tr>
<tr>
<td><strong>Breaks between lessons</strong></td>
<td><strong>Evaluate</strong>: Observing and documenting the rustproofing process</td>
<td>P1, P3 and P5</td>
<td>Breaks</td>
</tr>
<tr>
<td><strong>Lesson 6</strong></td>
<td><strong>Explain</strong>: Explaining and sharing group work</td>
<td>P2, P3 and P5</td>
<td>Class</td>
</tr>
<tr>
<td><strong>At home</strong></td>
<td><strong>Extend</strong>: Consolidating and extending knowledge related to rustproofing</td>
<td>P5</td>
<td>Home</td>
</tr>
</tbody>
</table>

Note: P1 = working on real problems; P2 = encouraging diverse ideas; P3 = providing collaborative opportunities; P4 = using authoritative sources constructively; P5 = performing a formative assessment.

Table 4 shows that the teacher flexibly adopted different principles at different stages of the science inquiry. We also asked the teacher to reflect on his pedagogical plan and enactment process and outcomes based on guided questions on the inquiry-based learning approach and instructional principles, and arranged a time to interview him to hear his reflections. Some of the questions (Q) and excerpts from his reflections (R) are presented as follows:

Q1: When teaching the rustproofing learning unit, do you think it is important for the students to conduct hands-on experiments in an authentic environment? Why?

R1: *If I told the students the reasons for rusting and how to prevent rusting directly, it would take 3 minutes. However, by providing opportunities for the students to lead their own science inquiry, they not only tested their own hypotheses in the experiments, but also underwent a process of discovery and collaboration: to identify problems in their everyday lives, raise questions to explore resources and conduct experiments to solve the problems.*

Q2: Did you encourage the students to express their diverse ideas in their inquiry? How?

R2: *I valued each student’s questions. How? Digital technology and the Internet extend our learning spaces. I seldom asked students to ask questions face to face in class. They could post their questions anytime, anywhere to the Edmodo social network platform, both inside and outside the classroom. They can get quick feedback from their peers or from me. If I found that many students were concerned about a problem, I would discuss the problem in class. Using Edmodo, all students’ questions are treated equally and their learning is extended beyond the classroom. This can be called seamless learning.*

It is worth noting that the teacher’s good understanding of inquiry-based pedagogies and the principles of working on real problems and encouraging diverse ideas allowed him to apply the instructional principles in his pedagogical practices in multiple contexts, with the support of the social network platform.

**Effect on students’ domain knowledge gains and inquiry skills development**

We investigated the effect of principle-based pedagogical design on students’ domain knowledge gains through pre- and post-domain tests on rustproofing. Table 5 shows the results of the tests. Significant differences were found between the pre- and post-domain test results (pre-average score = 11.64; post-average score = 22.50, *p* < 0.05). We can thus conclude that the students made significant advancements in their rustproofing knowledge after their inquiry.

<table>
<thead>
<tr>
<th>Class</th>
<th>No. of students</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>S.D.</td>
<td>M</td>
</tr>
<tr>
<td>4C</td>
<td>27</td>
<td>11.64</td>
<td>2.652</td>
<td>22.50</td>
</tr>
</tbody>
</table>

Note: Total test score = 40

*p* < .05
In terms of the rustproofing learning unit assignments, the average scores for the 27 students were 79% (7.11 out of 9 questions in total). Although some of the students’ scores were not high, their worksheets revealed that in many cases marks were deducted due to incorrect rendering of Chinese characters rather than their content knowledge. Figures 3(a) and 3(b) show screen captures of two students’ worksheets marked by the teacher. Figure 3(a) shows that the student used the incorrect Chinese word “份 (part)” rather than “分 (component)” – the two words are the same in Pinyin, and their characters are also similar. Figure 3(b) shows that one student did not know how to write the Chinese word “滅 (extinguish).”

![Figure 3. Screenshots of a student’s worksheet (a – left; b – right)](image)

The effect of the principle-based pedagogical design on students’ inquiry skills was examined through pre- and post-questionnaire surveys. The results are shown in Table 6. They reveal that only the pre- and post-questionnaire results for item 1 (I know how to start thinking about how to solve a scientific problem) (mean = 4.35) and item 10 (I know how to explain my ideas to my peers when learning science) (mean = 4.16) showed significant differences. Items 1 and 2 relate to the “questioning” and “explaining” inquiry skills, respectively, and indicated an improvement in the students’ skills in raising questions and explaining ideas and concepts to peers.

<table>
<thead>
<tr>
<th>Question</th>
<th>Pre-test M</th>
<th>Pre-test SD</th>
<th>Post-test M</th>
<th>Post-test SD</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I know how to start thinking about how to solve a scientific problem</td>
<td>3.77</td>
<td>0.652</td>
<td>4.35</td>
<td>0.689</td>
<td>4.573*</td>
</tr>
<tr>
<td>2. I know how to solve a scientific problem step by step</td>
<td>3.88</td>
<td>0.816</td>
<td>4.31</td>
<td>0.736</td>
<td>2.026</td>
</tr>
<tr>
<td>3. I know how to find scientific problems that I am interested in solving</td>
<td>4.08</td>
<td>0.935</td>
<td>4.15</td>
<td>0.967</td>
<td>0.440</td>
</tr>
<tr>
<td>4. I know where to find the information to solve a scientific problem</td>
<td>4.00</td>
<td>0.980</td>
<td>4.27</td>
<td>0.778</td>
<td>1.272</td>
</tr>
<tr>
<td>5. I know how to explore information/resources on my own when solving a scientific problem</td>
<td>3.96</td>
<td>0.824</td>
<td>4.08</td>
<td>0.935</td>
<td>0.486</td>
</tr>
<tr>
<td>6. I know how to improve the ways to solve a scientific problem</td>
<td>3.88</td>
<td>0.864</td>
<td>4.27</td>
<td>0.778</td>
<td>1.917</td>
</tr>
<tr>
<td>7. I know how to try different ways of solving a scientific problem</td>
<td>4.13</td>
<td>0.850</td>
<td>4.13</td>
<td>0.992</td>
<td>0.000</td>
</tr>
<tr>
<td>8. I know when to ask help from my peers when learning science</td>
<td>4.04</td>
<td>1.076</td>
<td>4.08</td>
<td>0.977</td>
<td>0.132</td>
</tr>
<tr>
<td>9. I know when to ask help from teachers when learning science</td>
<td>3.88</td>
<td>0.900</td>
<td>3.88</td>
<td>1.191</td>
<td>0.000</td>
</tr>
<tr>
<td>10. I know how to explain my ideas to my peers when learning science</td>
<td>3.72</td>
<td>0.891</td>
<td>4.16</td>
<td>0.987</td>
<td>2.290*</td>
</tr>
<tr>
<td>11. I know how to explain my ideas to my teacher when learning science</td>
<td>4.24</td>
<td>0.970</td>
<td>4.20</td>
<td>0.957</td>
<td>-0.146</td>
</tr>
<tr>
<td>12. I know how to work together with my peers to solve a scientific problem</td>
<td>3.88</td>
<td>1.035</td>
<td>4.29</td>
<td>0.806</td>
<td>2.005</td>
</tr>
<tr>
<td>Total</td>
<td>3.87</td>
<td>0.900</td>
<td>4.15</td>
<td>0.899</td>
<td>1.973</td>
</tr>
</tbody>
</table>

*p < .05

Ways that the students advanced their domain knowledge and developed their inquiry skills

We traced the artefact development of each student group in the rustproofing learning unit. Each group designed three methods. Among the 18 experimental methods proposed by the groups, only one method (i.e., using paint to coat the clip) was the same between two groups. All of the other methods were different from each other (see Table 7). In addition, after tracking the experiment outcomes, the degree of rusting in each method was evaluated and scored from 0 (no rusting) to 10 (most severe rusting), which is also shown in Table 7.
### Table 7. Experimental designs and rustproofing outcomes by group

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of design</th>
<th>Hypothesis of rustproofing theories using the methods. (All of the following methods were hypothesised to prevent air from entering the cup or to prevent water from having direct contact with the clip.)</th>
<th>Degree of rusting</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>(1)</td>
<td>Use Vaseline and paint to coat the clip and put oil into the cup along with the water.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>Use Vaseline to coat the clip.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>Use paint to coat the clip.</td>
<td>7</td>
</tr>
<tr>
<td>G 2</td>
<td>(1)</td>
<td>Use Vaseline to coat the clip and then wrap the clip with plastic wrap. Put oil and water into the cup.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>Use Vaseline to coat the clip and then wrap the clip with plastic wrap. Put oil into the cup.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>Use Vaseline to coat the clip and then wrap the clip with plastic wrap.</td>
<td>3</td>
</tr>
<tr>
<td>G 3</td>
<td>(1)</td>
<td>Put the clip into a storage bag.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>Use Vaseline to coat the clip, and then use the dryer to dry the clip before putting it into the water.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>Use a candle to dry the clip after removing it from the water.</td>
<td>3</td>
</tr>
<tr>
<td>G 4</td>
<td>(1)</td>
<td>Wrap the clip with glue paper.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>Wrap the clip with plastic wrap.</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>Put oil into the cup.</td>
<td>2</td>
</tr>
<tr>
<td>G 5</td>
<td>(1)</td>
<td>Use Vaseline to coat the clip and then put oil and soya oil into the cup.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>Use Vaseline to coat the clip and then put oil into the cup.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>Wrap the clip with glue paper and then put the oil into the cup.</td>
<td>7</td>
</tr>
<tr>
<td>G 6</td>
<td>(1)</td>
<td>Use paint to coat the clip, seal the clip inside a bottle and then put the bottle into the water.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>Use paint to coat the clip, use a dryer to dry the paint, seal the clip inside a bottle and then put the bottle into the water.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>Use paint to coat the clip.</td>
<td>7</td>
</tr>
</tbody>
</table>

We also examined the students’ captured photos daily to keep an observational record of the three experiments in each group. We obtained some of the artefacts created by Group 2 as an example. Figure 4(a) shows a screenshot of the three experimental results on the first day using the three methods (see Table 7). Figure 4(b) shows a screenshot of the experimental results on the last day (1 week after). Figure 4(c) shows the degrees of rusting (0-10) in the group’s three methods, evaluated by the group itself, peers in other groups and the teacher (3, 0 and 0, respectively). These artefacts documented the students’ deepened understanding of rustproofing from experimental design through to observation, presentation and evaluation.

![Figure 4](image_url)

*Figure 4. Photo of the first day of the experiment; photo of the second day of the experiment; photo of the experimental results evaluation (a – left; b – middle; c – right)*

Group 2 was chosen as having the best experimental rustproofing design, and was awarded a badge declaring its members rustproofing “experts,” which encouraged the students to make further science inquiry. It is worth noting
that although the students captured photos of the experimental results each day, they rarely entered observational records on the degree of rusting into the “Observational Forms for Rustproofing Experiments.”

To examine how the students advanced their inquiry skills, we investigated students’ inquiry processes supported by Edmodo, where seamless learning across physical spaces (in the classroom and between lessons using tablet PCs, and at home using various devices) and individual and social spaces (online learning and class interactions) was documented. Figure 5 indicates the limited numbers of students’ posts on Edmodo relating to their science inquiry skills (questioning = 1.7%, exploring = 2.2%, explaining = 5.1%, evaluating = 3.9% and extending = 0%). However, other posting categories accounted for the majority of the contributions: coordinating the experimental designs and observations (47.9%), social interactions (23%), greetings (14%) and news sharing (8%). This indicates that the social network platform played an important role in students’ project work orchestration and establishment of intimate relationships.

<table>
<thead>
<tr>
<th>Inquiry skills</th>
<th>No. (%) of postings on Edmodo</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questioning</td>
<td>7 (1.7%)</td>
<td>What shall I use in order not to make the oil not spill over?</td>
</tr>
<tr>
<td>Exploring</td>
<td>9 (2.2%)</td>
<td>How many ways are there to prevent rusting (with Hyperlink)?</td>
</tr>
<tr>
<td>Explaining</td>
<td>21 (5.1%)</td>
<td>This is the method of using oil to prevent rusting (Hyperlink: iron rusting -  Wiki – Wikipedia - the free encyclopedia)</td>
</tr>
<tr>
<td>Evaluating</td>
<td>16 (3.9%)</td>
<td>Good!</td>
</tr>
<tr>
<td>Extending</td>
<td>1 (0)</td>
<td>Gilded iron or metal can prevent rusting</td>
</tr>
<tr>
<td>Others</td>
<td>355 (86.7%)</td>
<td></td>
</tr>
<tr>
<td>Coordination</td>
<td>196 (47.9%)</td>
<td>Chu L., don’t forget to bring the hair dryer.</td>
</tr>
<tr>
<td>Social interaction</td>
<td>94 (23%)</td>
<td>You get my phone, Ho Y?</td>
</tr>
<tr>
<td>Greetings</td>
<td>61 (14.9%)</td>
<td>Good morning, everyone!</td>
</tr>
<tr>
<td>News sharing</td>
<td>8 (2%)</td>
<td>The second group got the honor of “Rustproof Experts”.</td>
</tr>
<tr>
<td>Total postings</td>
<td>409 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 5. Categories of students’ posts on Edmodo related to rustproofing and other inquiry skills*

We also interviewed a group of students using the questions guided by the five elements in the inquiry-based learning model to understand their rustproofing inquiry processes. The students expressed great passion for leading their own rustproofing research in real life (supported by Edmodo), where their inquiry experience bridged seamlessly across different spaces. One student made the following statement.

In the past, in science class, we only learned from textbooks. It was boring. Now, we can explore and discuss the best ways for our experimental designs on rustproofing. It is interesting that we can do hands-on experiments ourselves, observe the process of the rustproofing process and take pictures [of the clip rusting results] day by day . . . If I learned [rustproofing] from textbooks, it would be easy for me to forget what I have learned. But doing hands-on experiments makes it difficult to forget the methods and principles [of rustproofing]. I understand the rustproofing theories better.

The students’ interview results indicate that they acquired solid domain knowledge and developed inquiry skills from the experience of hands-on experimental design and practice.
Discussion

Principle-based pedagogical design—gains

This study attempted to develop and implement a principle-based pedagogical design for inquiry-based learning in the seamless learning environment of a Hong Kong primary school. The results show that a teacher with training experience and a good understanding of the principles and inquiry-based learning model was better able to plan and enact student-centred inquiry activities in which students had control over their own learning. This echoes the findings in previous studies that suggest that enhancing teachers’ inquiry-based pedagogical competence in a technology-supported learning environment requires teachers to understand the basic theoretical principles behind inquiry-based pedagogies and how to apply the principles to pedagogical practices (Scardamalia, 2002; Song & Looi, 2012, Zhang et al., 2011). In our study, the students showed improvements in their domain knowledge learning and inquiry skills, especially in terms of “questioning” and “explanation,” which are considered essential elements of inquiry-based learning (Hakkarainen, 2003).

However, students cannot develop a meta-cognitive awareness of inquiry strategies without adequate scaffolding (Lakkala et al., 2005). Our study adopted a guided inquiry-based learning model by providing prompts (“Forms for Experimental Rustproofing Designs” and “Observational Forms for Rustproofing Experiments”) for the students’ experimental designs and observations. Although each group of students generated different experimental designs and hypotheses, they were all on the right track in the inquiry. According to Lin and Lehman (1999), metacognitive skill development is typically fostered by providing students with opportunities to reflect on and monitor their learning performance and revise their investigative strategies. In this regulative process, students are reflective inquirers looking to accomplish projects and gain a deeper understanding of domain knowledge and inquiry skills (Loh et al., 2001). Further, in the “Forms for Experimental Rustproofing Designs,” the students were required to take on different responsibilities in completing the experiment, which increased their awareness of taking collective responsibility for advancing the group’s knowledge (Scardamalia, 2002; Zhang et al., 2011).

In this study, the Edmodo social network platform provided a seamless learning environment for the students to coordinate the inquiry projects and establish a rapport in groups and with peers, which played an important role in advancing their rustproofing knowledge and developing their inquiry strategies. In addition, the students could share their groups’ products with their peers at any time and anywhere on the platform, which allowed them to evaluate other groups’ work and construct knowledge collaboratively. The embedded peer group assessment in the pedagogical design meant that the assessment responsibility was turned over to the students, helping them to develop increased agency when evaluating their own learning progress (Zhang et al., 2011). The students could also submit assignments to the platform and obtain the teacher’s feedback in a timely manner, which encouraged them to learn. This study contributes to the literature on the use of principle-based pedagogical design for guided inquiry-based learning in science in a seamless learning environment at primary level. Nevertheless, it also has some limitations.

Principle-based pedagogical design—losses

We identified several issues and limitations to be addressed in future work. First, in terms of the five instructional principles adopted in the research, the teacher was not able to grasp the gist of the principle of using authoritative information constructively in his reflections. Some students copied and pasted information from the Internet directly without acknowledging the source. However, the teacher believed that as long as he asked the students to explore learning resources on the Internet, he was adhering to the principle. He did not further scaffold the students on making constructive use of sources. According to Yeo and Tan (2010), the constructive use of authoritative sources involves the interpretation of meaning in context and plays an important role in deepening and expanding students’ science domain knowledge. Hence, in our next cycle of research, we must elaborate this principle to the teacher. Second, the teacher designed the ‘Observational Forms for Rustproofing Experiments’ (see Appendix II) for the students to document the daily degree of rust over five consecutive weekdays. The findings show that none of the six groups completed this task. The ‘Degree of rusting of the iron clip: 0/10’ item might have been too abstract for Primary 4 students to estimate and record. Nevertheless, the students took some pictures to document the daily rusting process during their break time. In providing scaffolds such as prompts, we suggest that the teacher must
consider the students’ level and cater to their needs. Finally, the results of the research cannot be generalised due to the short time span. Further interactive studies are required to investigate whether the five instructional principles suffice for developing teachers’ principle-based understanding of inquiry-based learning, whether the inquiry-based learning model must be refined and how to make better use of social network technology to support seamless learning environments.

Conclusions and future work

This study explores the use of a principle-based pedagogical design for inquiry-based learning in a seamless learning environment, with resource access and peer interactions initiated in classrooms and extended to online interactions. The inquiry-based learning approach was integrated into the domain knowledge learning process to promote students’ development of inquiry skills. The results demonstrate the effective development and implementation of the pedagogical design in a rustproofing learning unit and the positive effect of the design on students’ domain knowledge gains and inquiry skills. The results reveal the need for further research to accumulate experience and scale-up pedagogical interventions within and across schools. The future scale-up of research efforts should be planned under the “design-based implementation” and “designing for diffusion” approaches (Dearing & Kreuter, 2010; Penuel, Fishman, & Cheng, 2011) to build capacity among teachers in the within- and cross-school settings. Further research will instil in target teachers a positive perception of the research efforts that address persistent practice problems from multiple perspectives during the capacity scale-up across the Hong Kong primary school sector.

References


### Appendix I
Forms for experimental rustproofing designs

<table>
<thead>
<tr>
<th>Group:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group members:</td>
</tr>
<tr>
<td>1.</td>
</tr>
<tr>
<td>2.</td>
</tr>
<tr>
<td>...</td>
</tr>
</tbody>
</table>

*Experimental design 1 (Experimental designs 2 and 3 used the same forms as experimental design 1.)*

<table>
<thead>
<tr>
<th>Material (in order)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>1.</td>
</tr>
<tr>
<td>2.</td>
</tr>
<tr>
<td>...</td>
</tr>
</tbody>
</table>

Design diagrams (in order)

### Appendix II
Observational forms for rustproofing experiments

<table>
<thead>
<tr>
<th>Observation date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation time</td>
</tr>
<tr>
<td>Observer(s)</td>
</tr>
</tbody>
</table>

*Experimental design 1 (Also experimental designs 2 and 3)*

| Degree of rusting of the iron clip: 0/10 |