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Analysing the Mediating Processes of Teacher's Growth: A Case Study in a Seamless Inquiry Science Learning Environment

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Abstract: *This paper reports a case study that is intended to trace the professional growth of a science teacher who is implementing seamless inquiry science learning (SISL) in the context of Singapore primary school. In particular, we analyse the teacher's learning trajectory under the lens of the Interconnected Model of Teacher Professional Growth (IMTPG). The teacher's pedagogical practices were investigated at the beginning of the intervention, and the changes in his practices were monitored throughout the ongoing teacher professional development (TPD). The findings reveals the importance of TPD design through two significant relationships: from external domain (ED) to domain of practice (DP), and from external domain (ED) to personal domain (PD), throughout the implementation of SISL. Recognising the importance of the design of an effective TPD, IMTPG was used as an analytical tool to analyse the corresponding relationships among the aforementioned domains in investigating the teacher's growth in term of the pedagogical changes. The reciprocal relationship between the desired outcomes of the TPD and the teacher's growth informed by the effective mechanisms used in conducting TPD, which is "learning by doing". Thus, the design of an effective TPD to facilitate teacher's growth should consider the desired "learning outcomes" and the endurance of that change to transform the innovative pedagogy.*

Keywords: Seamless inquiry science learning (SISL), Interconnected Model of Teacher Professional Growth (IMTPG), teacher's growth

1. Introduction

Recent literature highlights there are a wealth of varied opportunities for learning science in informal settings can provide for the learners (Bricker & Bell, 2014; Rahm & Moore, 2016). With the proliferation of mobile and social media technology that can be used for learning purposes, educators are becoming more excited about harnessing the technological affordances for supporting science learning (Zhang et al., 2010). In this regard, the notion of seamless learning offers a potentially effective means that promotes synergistic and continuous learning with learners appropriating various *in-situ* resources for learning and interactions across multiple contexts and time scales.

To facilitate the emerging notion of seamless learning (Wong & Looi, 2011; Wong, Milrad, & Specht, 2015), educational researchers stress the impact of teacher professional development (TPD) on teacher knowledge and practice, which consequently affects students' learning outcomes (Borko, 2004). Most of the TPD shared a common purpose, for instance to alter the professional practices, beliefs, and understanding of school personnel toward an articulated end (Griffin, 1983). It was reported that one of the reasons of failed TPD is that the school leaders neglect to take into account existing knowledge about how teachers learn (Borko, 2004). The purpose of this study is to move these contributions forward in emphasising the significance outcomes of TPD with respect to the teacher's growth through IMTPG-informed relationships, which offered an entry point for further conceptualising analysis.

2. Literature Review and Theoretical Underpinnings

2.1. The Pedagogical Design of Inquiry-based learning to SISL in Primary Science

Inquiry-based learning has been advocated in science pedagogical practices which is defined as a knowledge construction process in an authentic context (Song & Kong, 2014). However, the constraints of time and learning context is one of the challenges of inquiry-based learning. The extension of the science learning environment facilitates students to investigate authentic scientific phenomena and to demonstrate scientific knowledge across the contexts (Shih, Chuang, & Hwang, 2010). The learning experiences are seamlessly integrated into their daily life. Typical seamless learning environments comprise of technology-enhanced classrooms, online interactions, as well as the ubiquitous infrastructure that enables learners to appropriate various resources and digital tools for purposeful learning (Looi et al., 2011). The advancement of technologies are receiving increased attention from the science education community due to their potential to support new forms of inquiry (Edelson, Gordin, & Pea, 1999). The teacher's effective implementation of SISL is conducive to students' scientific knowledge construction and fostering of 21st century competences.

2.2. Teacher Professional Development (TPD) and Teacher Change

Leithwood (1990) identified a spectrum of expertise across teachers' careers, beginning with novices who focus on survival skills (e.g. classroom management), progressing to instructional competence implementing school-wide practices, followed by expanding instructional flexibility, and culminating with instructional expertise and critical reflection about teaching. Studies also found that teachers move through these stages at varying paces dependent upon their unique needs, interests, and abilities (Leithwood, 1990). Teachers see TPD as the most readily available routes to growth on the job (Fullan, 1993), a pathway to increased competence and greater professional satisfaction (Huberman, 1995). Thus, to evaluate the teacher's growth, more efforts should be placed on investigating teacher's change on the lesson enactment and their involvement in TPD to enhance their teaching competency in addressing the students' needs.

2.3. The Interconnected Model of Teacher Professional Growth (IMTPG) as an Analytical Tool

The IMTPG models teacher's change as mediated by the processes of reflection and enactment from four domains (Clarke & Hollingsworth, 2002). First, the personal domain (PD) is defined as the teacher's knowledge, beliefs and attitudes towards a given pedagogical approach. Second, external domain (ED) refers to the TPD related to the pedagogical approach that the teacher participates in. Third, the domain of practice (DP) is the actual enactment of the pedagogical approach. Lastly, the domain of consequence (DC) indicates the outcomes of the implementation of the pedagogical approach that characterises the domain of practice (e.g., student's engagement level).

The IMTPG model can be employed as an analytical tool to characterise the teacher change data in terms of ''the empirical identification of the processes by which change in one domain is associated with changes in another. The key change domains and mediating processes highlights the particular aspects that significantly contributes to an effective TPD program (Clarke & Hollingsworth, 2002). The operationalisation of each domain and the multiple interconnections between different domains explicitly demonstrates the teacher's growth (see Figure 1).

The motivation of using this framework is that it gives recognition of the teacher's growth as an idiosyncratic process. The scholars identified the nine relationships among the domains for understanding the development of science teachers' knowledge (Justi & Driel, 2006). For the purpose of our case study analysis, we adapted the model by systematically categorising the relationships with the established criteria into the process of enactment and reflection (see Table 1). This framework is applied to analyse significant relationships among the domains in evaluating the teacher's growth and to support teacher in the implementation of SISL.

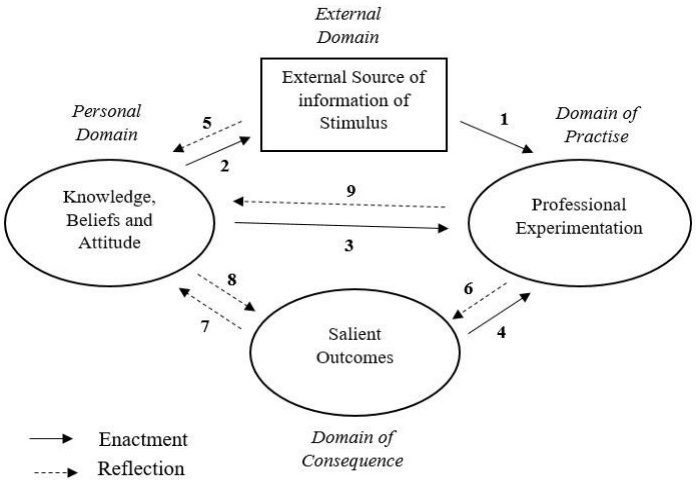

Figure 1. Interpreting the interconnected model of professional growth (entries in each domain are illustrative example). (adapted from Clarke & Hollingsworth (2002, p. 957)).

3. Methodology

Qualitative case study methods were adopted (Merriam, 2001) as our study sought to explore the interaction between multiple domains that affected participants' change over time. Descriptions of the context, profile of participants, data sources and analysis are provided in the next subsections.

3.1. Context of School and Project

The study was intended to investigate the development of a scalable mobile and technology-integrated SISL in Primary 4 classroom setting. This paper focuses on tracking the teacher's growth in the project. There are three teachers participated in the pilot study. They were actively involved in designing, implementing the lesson and all the TPD sessions. In order to achieve depth rather than breadth in terms of demonstrating the SISL teaching practices, we only include the case study of one pilot teacher, Paul (pseudonym). Thereafter, we provide a summary of the 6-month study.

The introductory workshop in February 2017 covered the basic concept and design principles of seamless learning and exemplifying lesson plans. The ongoing TPD-cum-lesson-enactment period took place between March and August 2017 and consisted of three seamless lesson design-enactment-review cycles (i.e., with intertwining TPD sessions, lesson implementations and post-implementation debriefing), covering the curricular topics of Light and Shadow, Heat Transfer, and Effects of Heat respectively. Each seamless lesson typically lasted two weeks and comprised the instructional activities that were weaved together to form a technology-integrated, cross-temporal and cross-spatial (i.e., in and out of classroom) trajectory of learn-apply-reflect. The students' learning processes as laid out in the lesson plans included teacher facilitated in-class contextual learning, student-initiated and technology-integrated learning beyond the class (access to the online social platform with any mobile devices) and teacher facilitated in-class consolidation. The post-intervention consolidation workshop in September 2017 constituted high-level formative reviews and reflects the actual enactments across the learning cycles, challenges of the pedagogical approaches, students' learning outcomes as well as co-construction of new teaching strategies. The comparison of the enactment in the first and third cycles will be discussed in the following subsection.

3.2. Profile of Participating Teacher

Paul graduated as an microelectronic engineer and has four years of experience in teaching science. He holds a strong belief of pedagogical inquiry-based learning throughout his professional practices in facilitating and motivating the mixed-performing pilot class with a high level of engagement. Despite new to SISL, he demonstrated confidence and passion in teaching as he integrated his pedagogical approaches in implementing the SISL (see Table 2).

3.3. Data Sources and Analysis

In our study, the transcriptions of post-interviews, ongoing TPD minutes and teacher's reflection during ongoing TPD sessions are the primary data for outlying perspectives. By using the hermeneutic approach (Squire, 2008), we hope to operationalise the qualitative study of teachers' growth by emphasising specifically at: 1) Which processes lead to the connection of different domains in transforming the teacher's growth? 2) What are the relationships among various IMTPG domains that characterise the teacher's growth in implementing SISL? The outcomes of our analysis to address both questions will be posited in the following sub-sections.

3.3.1. Identification of the meaning of each relationship of the IMTPG in this study

Linking our study to the IMTPG model, we developed criteria to identify its meaning according to the context of our study which were then used in data analysis. The ED (TPD) included regularly scheduled ongoing TPD and post-intervention consolidation workshop. The ongoing TPD sessions focused on the teachers' pedagogical changes and micro-teaching issues to facilitate DC (the students' learning outcomes). The post-intervention consolidation workshops provide a platform for teachers to share and reflect their PD (initial opinion towards SISL) and DP (SISL teaching practices). By assuming that the ED is the most important platform in supporting the implementation of SISL and evaluating the teachers' growth, we focused on the relationships 1 and 5 (see highlighted in Table 1).

Table 1 Criteria for the establishment of the relationships in the IMTPG in our study.

Adapted from (Justi & Driel, 2006).

No.	Relationship	Criteria for establishment
Enactment		
1	From ED to DP	The TPD discussion influenced the teaching practices.
2	From PD to ED	When a teachers' initial opinion towards SISL influenced the TPD discussion.
3	From PD to DP	When a teachers' initial opinion towards SISL influenced the teaching practices.
4	From DC to DP	The teacher reflected on the learning outcomes and changing the teaching practices.
Reflection		
5	From ED to PD	The discussion during the TPD modified the teacher's initial opinion towards SISL.
6	From DP to DC	The teaching practices caused a specific learning outcome.
7	From DC to PD	The teacher reflected on the learning outcomes, changing initial opinion towards SISL.
8	From PD to DC	The teachers' initial opinion towards SISL help in reflecting the learning outcomes.
9	From DP to PD	When a teacher's teaching practices modified his or her initial opinion towards SISL.

4. Findings and discussion

4.1. The IMTPG as an Analytical Tool to study the Teacher's Growth

The distinction between the change sequence (superficial change) and the growth network (more lasting change) is important in TPD. However, our study could not consider the criterion of "more lasting change" due to the brief period of data collection. Therefore, we focus on two mediating processes, namely enactment and reflection, to address the teacher's change sequence which was triggered by the connections among different domains in transforming the teacher's growth network. The enactment and reflection are the mediating processes that triggered the change effect (Justi & Driel, 2006).

4.1.1. Mediating process: Enactment of SISL

We propose the criteria based on our context, which is not simply "acting" but differentiating by putting into new professional practice or belief. Paul implemented the technology-integrated SISL in his lesson (Arrow 1 in Figure 1). During the ongoing TPD, he shared his personal practices, which triggered further discussion, "There are lower real-life

applications in my previous teaching but the SISL promotes authentic learning." (Arrow 2) His colleague Jess (pseudonym) added, "You are right. We also need to address the scientific concepts in the correct sequence to enhance their understanding after the students are exposed to their real-life application." *(Jess, 17 July- Ongoing TPD)* As Paul held strong beliefs in inquiry-based learning, he found that the technology-integrated SISL enhances learning ownership and motivation across various contexts (Arrow 3). He said, "I was impressed when the student learned from YouTube and explained the concept of heat gain which is only covered in the curriculum of secondary school physics." The students' response motivated him to persist his belief in implementing technology-integrated SISL in a long-term duration (Arrow 4). He reflected, "I will continue this approach as it leads to offline brainstorming, which saves our time." *(10 October 2017- Interview)*

4.1.2. Mediating process: Reflections throughout the Enactment of SISL

In our study, we adopt the term "reflection, active, persistent and careful consideration" (Dewey, 1910). From the interview, we found that Paul acquired new ideas from the TPD, which were subsequently implemented and thus reflected upon his teaching practices. After discussion with the Head of Department of the science subject, Paul modified his instruction by facilitating "thinking routines" (reflect and learn) to guide students' thinking (Arrow 5). He said, "Students did post information out of the syllabus; but they bombarded the online social platform. The purpose of 'thinking routine' is to guide them to think, such as, 'I agree because...' before we seek for their real-life application." *(21 August 2017- Ongoing TPD)*

Throughout the lesson implementation, reflections and analysis of the students' responses that he valued, Paul drew a conclusion that it took time to enculturate students' learning in informal settings. (Arrow 6) He said, "For the post-learning consolidation, I think that is the culture building. I can't do it now; maybe next year." *(10 October 2017- Interview)* We acknowledged Paul's value in terms of the significance of the "Salient Outcomes" in different salient situations. Initially, Paul realised his questioning technique resulted in very low participation which stimulated him to modified his teaching approach by assigning authentic tasks to enhance SISL (Arrow 7). He reflected:

> To increase the students' engagement, more real-life application tasks and more divergent questions were given. Previously, I posted direct questions, for example, "How many types of heat transfer?" I have modified the approach in SISL practice, I shared a video about baking a cake (the cake was put on a plate and bake with oven). The video acts as a stimulus (thinking point), students were asked to interview their parents to find out whether the cake or the hotplate is hotter and express their ideas on online social platform**.** *(21 August 2017 – Ongoing TPD)*

Students are engaged through authentic activities to find out their inquiries. "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science. Inquiry as a learning activity, where the students develop scientific knowledge and understand how scientists study the natural world." (Council, 1996) There are two reflective links postulated in this model. The initial reflective link relates the changes in the teacher's belief that lead to a re-evaluation of changes in the domain of consequence. The final reflective links is pertaining to the relationship between the modified practice and the salient outcome (Clarke & Hollingsworth, 2002). In our study, the initial reflective link was emerged when Paul was aware of the students' low online participation and thus he planned to articulate the parents' roles in informal learning setting (Arrow 8). He argued, "We need to conduct a meet-the-parents session before the next lessons are implemented." *(21 August 2017- Ongoing TPD)* The final reflective link was evidenced when Paul modified his initial idea by getting parents involved in the second online discussion (Arrow 9). He reflected: "The rate of participation in second online meeting is so much higher because we issued invitation slips to get the parents' attention. Parents need to realise the beauty of teachnology-integrated SISL." *(10 October 2017- Interview)*

4.2. IMTPG as an Analytic Tool to study the Impacts of TPD across Different Domains

The analytical function of the IMTPG is used to address our second research question in investigating the relationships among different domains that characterise the teacher's growth with the implementation of SISL. As we focus on relationships 1 and 5, there are clear evidences that the ED contributed to the PD and DP, in different degrees, to the teacher's professional growth as explicated below.

4.2.1. Impacts of TPD on teacher's growth: Lesson Design to the Implementation of SISL (from ED to DP)

During the post-intervention consolidation workshop, Paul reflected on his teaching strategies and focused on potential impacts of these strategies. Paul modified the element of his practice after his exploration in an informal sharing session with a teacher from another school, Susan (pseudonym). The quotation reflected he had come to realise some ideas, "Susan used the thermal camera in the experiment. Due to our laboratory's limited resources, I took the optical one which we use to measure our forehead, I measure the temperature before the experiment started." *(10 October 2017- Interview)* In addition, Paul modified the lesson design from a guided-inquiry to a more open-inquiry after discussing with the researchers.

Table 2 compares and contrasts the lesson enactment in the first and the third learning cycles. Firstly, during the first cycle, Paul provided prompt questions to guide the students before the experiment; whereas during the third cycle, Paul allowed the students to design and comment on their peers' scientific experiments to establish learning ownership. Secondly, in the perspective of technology-integrated learning, the students may work individually in filling in the KWL[1] chart after the school and yet such an activity did not promote further discussion; whereas the online journaling in the third cycle promoted peer discussion.

Table 2 Comparison of lesson enactment: from teacher-guided shadow making experiment to self-designed magic bag experiment

Lesson enactment in first cycle	Lesson enactment in third cycle
Lesson objective: Investigate the variables that affect shadows formed and communicate findings. **Part 1: Introducing the topic** - The teacher asked the students to work in groups to fill up the K field of the KWL using their laptops on what they know about light and shadow. Then, each group are invited to share their knowledge. - The students thought of the following questions: 1. How shadows are formed? 2. How do they make shadows of different shapes and sizes? **Part 2: Conducting the scientific investigation** - The teacher brought the students to the parade square in the school compound to use their hands to make different shadows in groups. They need to observe different shadows formed. - Students filled up the W field of the KWL using their	**Lesson objectives:** Relate the effects of heat conduction through planning a scientific investigation. **Pre-lesson activity** – Online journaling (Group work) - Students discussed and improved their investigation-design a container, known as "magic bag". **Part 1: Setting up of the magic bag** - The teacher consolidated students' final designs for comparing the effectiveness in slowing the melting of popsicle. - In groups, students set up the materials based on their design. They will record the steps of the investigation. **Part 2: Conducting the scientific investigation** - Students tested out their investigations. They recorded the volume of liquid in the popsicle at the start and end of their experiment. **Part 3: Reflection Session** - Students reflected on the conduct of the scientific

[1] KWL: A technique that scaffolds students in activating prior knowledge, setting learning goals and encouraging learning (i.e., students to fill up "I Know", "I Wonder" and "I Learned" before, during and after a learning process).

laptops. They can continue to do so at home.	investigation (strength and areas of improvement).

4.2.2. Impacts of TPD on teacher's growth: A Reflective Teacher: (from ED to PD)

During the post-intervention consolidation workshop, Paul reflected his initial opinion, personal instructional practices and contrasted it with his implementation of SISL. He said, "There was more collaborative learning occurred as they built on their peers' ideas by posting on the online social platform before the lesson. The class discussion became richer as they came to school with prior knowledge." *(19 September 2017- Workshop)* Furthermore, Paul described his concerns which contradicted with his initial opinion, as reflected in the dialogue during TPD session:

> Paul: I thought online meeting will engage them, but it is challenging to get them online beyond the school. It could be their learning attitude as the statistic revealed that they have the devices.
>
> Researcher: Perhaps you may need to sell the "beauty" of online task. You may project out their online work during the lesson to show your appreciation for their hard work. *(18 July 2017- Ongoing TPD)*

From such quotations that build upon the establishment of relationships 1 and 5, we conclude that there are significant relationships between ED and DP, and between ED and PD. The elements that contribute to the design of the ED (TPD) is highly important as it strongly influences the DP and PD, which were discussed in the next subsection.

4.3. Implication of the Teacher's Growth through the TPD in Implementing the SISL

In our study, we found that Paul was proactive in self-judging whether his implementation was aligned with the "desirable" characteristics of the seamless learning. He was actively participating in the lesson designing and reflection of his personal opinion and teaching practices. Through analysing the relationships 1 and 5, we found an effective mechanisms of "learning by doing" for the TPD design which promote teacher's growth with regard to the pedagogical development. Throughout the implementation of SISL, Paul designed, reviewed and modified the lesson design with his fellow teachers and researchers. Then, he shared his teaching reflection on the impact of SISL to the learning communities, for instance, the parents. Studies on TPD have shown that high-quality PD programs must entail a form of inquiry that enables teachers to actively construct knowledge through practice and reflection (Guskey, 2002).

5. Concluding remarks and future applications

In conclusion, the IMTPG was effectively used as a systematic framework to analyse the data using all nine aspects of teacher's growth. In this study, we detailed the IMTPG by focusing on the analysis of the nine relationships among the four domains through defined the criteria for the identification of the teacher's growth. The findings demonstrated there are two significant relationships (1 and 5) that supported the emergence of SISL practices, which also contributed to the effective design of TPD. This is particularly important as there is a lack of understanding of TPD in details, there is a need for research tools in this area (Beijaard, Verloop, Wubbels, & Feiman-Nemser, 2000).

We recognize the need for further study to substantiate the efficacy of the TPD by checking the transferability of our findings to the various school contexts and participants. Future research is needed to examine the impacts of TPD's learning outcomes on diverse participants' learning, motivation across learning contexts and to what extent explicit changes of instructional practices in the uptake of learning outcomes. It is our hope that the application of the IMTPG model will stimulate renewed interest in the transition from one domain to the next, the nature of the relationships between different domains, and the factors that affect the teacher's changes in a particular domain.

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