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Sociotechnical co-evolution of an e-Learning innovation network

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Abstract
This paper reports on a longitudinal study of a network of 10 special education needs schools over a span of 11 years that leveraged the opportunity offered by a government-funded e-learning pilot scheme initiative to further their efforts in providing the same educational opportunities to their students as those in mainstream schools. The trajectory of this network's evolution shows that its robustness lies in the joint leadership network among the schools, and the insight and agency that this leadership network exhibited in the intentional exploration and crafting of a social structure and mechanism to support innovative developments in technology and pedagogical innovation, which we refer to as sociotechnical co-evolution. By adopting a sociotechnical system framework to analyse the changes at the landscape, regime and niches levels, we show that in fact landscape factors play a crucial role in shaping the innovation trajectory through its influence on the niches. Network leadership, within-school leadership and organizational infrastructures evolve and play an important role in the co-construction of the sociotechnical regimes needed to bring about deep and widespread changes in pedagogical practice.

Introduction

The vision that technology use in teaching and learning will improve learning, and foster the development of 21st century skills underpins many IT in education policy initiatives around the world (eg, Singapore Ministry of Education, 2015; US Department of Education, 2016). On the other hand, the actual extent of e-learning adoption in classroom practices has been much less prevalent than expected (Collins & Halverson, 2009; Fraillon, Ainley, Schulz, Friedman, & Gebhardt, 2014). Even when ICT is used in teaching and learning, the pedagogical approaches adopted are largely traditional (Law, Pelgrum, & Plomp, 2008) and has not demonstrated positive association with students' achievements as measured in international studies (eg, OECD, 2015).

Studies show that pedagogy, not technology, has the greatest impact on the outcomes of e-learning implementation (Paniagua & Istance, 2018). It is also well recognized that teacher learning needs to encompass not only technical skills, but technological pedagogical content knowledge (TPCK) (Koehler & Mishra, 2008) for effective e-learning integration in the curriculum. Changes

Practitioner Notes

What is already known about this topic

- The success of technology integration in teaching and learning is predicated upon deep changes in pedagogical practice.
- Opportunities for teacher learning to acquire requisite technological pedagogical content knowledge (TPCK) and the availability of suitable e-learning resources are key factors for successful e-learning adoption.
- The architecture for learning (organizational structure, interaction mechanisms, reifications and technology use) in an innovation network plays an important role in the implementation and scalability of the innovation.

What this paper adds

- The application of a sociotechnical co-evolution framework originating from studies of system-wide technological transitions to examine the multilevel changes over time in an e-Learning innovation network.
- Significant efforts are needed to establish new sociotechnical regimes (rules) to guide changes in practice.
- An organizational structure comprising top and relevant middle management actors are needed to develop the necessary sociotechnical regimes.
- An important, but underexplored role of e-learning technologies is to institutionalize regulatory rules to bring about desired changes in practice.

Implications for practice and/or policy

- e-Learning technology policy and development should give priority to technologies that scaffold desired pedagogical and learning practices.
- e-Learning innovation network configurations should be designed to connect top and middle management actors, and change as the innovation focus evolves.

in teachers' pedagogical practices are generally outcomes of teachers' engagement in a process of technology-enhanced pedagogical innovation (TEPI) rather than the results of a simple replication or "adoption" process (Paniagua & Istance, ibid). Studies on teacher learning for the implementation of technology-enhanced learning have found teacher co-design of learning to be a very effective model (Kali, McKenney, & Sagy, 2015; Voogt *et al.*, 2015).

The challenge of sustainability and scalability has been a major theme in the pedagogical innovation literature (Looi & Teh, 2015). A systematic investigation of cases of technology-enhanced learning innovations from Europe and Asia to identify the conditions for scalability shows that what matters is not only teacher learning, but whether aligned learning takes place at multiple levels of the education ecosystem (Kampylis, Law, & Punie, 2013). In seeking ways to create scalable educational innovations, the learning sciences community identified the need to go beyond design-based research (Collins, Joseph, & Bielaczyc, 2004) to engage in design-based implementation research (DBIR, Fishman, Penuel, Allen, Cheng, & Sabelli, 2013), an action-oriented research approach that includes organizations and institutions that constitute the ecology within which learners and classrooms are situated. Evaluation studies of educational reform efforts at the district level (Stein & Coburn, 2008) also reveal that the impact and scalability of the same reform funded with comparable resources can be very different, depending on the architecture for

learning put in place to implement the change. Here, architecture for learning refers to the organizational environments, including organizational structures, mechanisms and collaboration technologies that foster aligned learning involving teachers and other educational professionals at different levels of the system.

In this paper, we report on a longitudinal study of a network of schools that has a history of over 10 years of self-organized collaborative innovation that arose out of an evaluation project associated with a government-funded e-learning pilot scheme. Our interest is to explore the scalability of TEPI from the perspective of understanding the necessary conditions for historical sustainability and system-level scalability of social practices brought about by technological innovations (teaching and learning being the focal social practice involved in TEPI). Hence, we have adopted a sociotechnical co-evolution perspective, which is a theoretical perspective that examines the historical sustainability and system-level scalability of social changes brought about by technological innovations from a sociological perspective.

Sociotechnical systems and technological transitions

Many sectors in the society have undergone major technological transitions involving significant ways in which the society functions, such as transportation, hygiene, waste disposal, etc. These transitions are far from being simple technological substitutions, but have to be accompanied by other changes such as infrastructure, user practices, regulations, technoscientific knowledge, etc. User practices can be viewed as routines or patterns of behaviour involving artefacts and skills, often embedded in organizations. Thus Rip and Kemp (1998) refers to technology as "configurations that work." Technological transitions cannot come about without human agency, and the engagement of compatible social and organizational structures. Studies of such transitions, often over decades, show that changes in the sociotechnical configurations is an evolutionary process. There is an inertia built into the existing configuration that established technologies are situated, which Nelson and Winter (1982) refer to as technological regimes. The evolutionary trajectory (Schumpeter, 1934) is populated by iterative cycles of change that may include organizational routines, markets, user preferences and new technologies and technological functions. Lie and Sørensen (1996) thus argue that evolutions in technological adoption is different from biological evolution in that the latter is a process of selection, while the former involves learning, adjustments and customization.

An evolutionary multilevel framework for conceptualizing technological transitions (TT) has been put forward in the technology studies literature (Geels, 2002; Rip & Kemp, 1998) to serve as an analytical heuristic for understanding the dynamics of sociotechnical change. The concept of levels in this framework (see Figure 1) is different from the multilevel framework used in the analysis of change in e-learning contexts (eg, Davis, Eickelmann, & Zaka, 2013; Law, Christensen, & Niederhauser, 2016) that focuses on individual and organizational actors that are hierarchical nested at different levels of the system. The TT analytical framework highlights the interactions and connections between the heterogeneous elements to reveal the dynamics behind changes in a sociotechnical system, which comprises three levels (Geels, 2002; Kemp, Rip, & Schot, 2001). At the top level is the sociotechnical landscape, which describes a broad range of external factors such as economic growth, political climate, cultural norms, etc that sets the context for the interactions of the actors. The next level is sociotechnical regimes, which refers to the sets of rules that guide the activities of different actors and social groups. These rules provide stability to the sociotechnical configurations. At the lowest level are niches, which are "spaces" that are sheltered from the prevalent regime and function as incubators for radical (as opposed to incremental) innovations (Schot, 1998). Niches provide the protection for experimentation and learning in the early phases of innovation, as well as in building the social networks that support innovations. Thus, niches

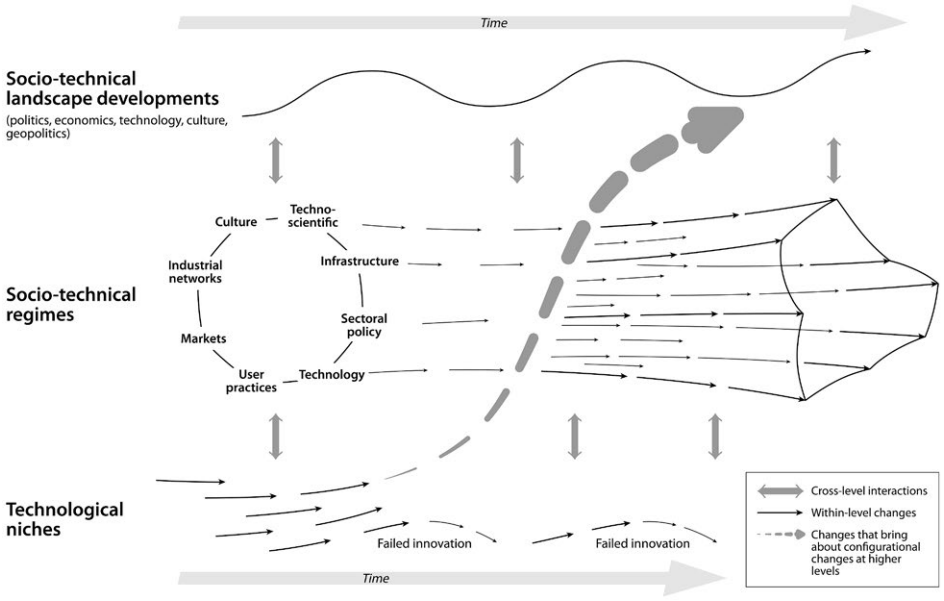

Figure 1: The sociotechnical change model according to Geels (2002)

constitute the micro-level that foster radical innovations and is the fastest changing of the three levels. Situated between niches and landscapes is the regime level, which maintains the relative stability of the sociotechnical configuration. Landscapes do change, but takes even longer than for regime changes to take place.This evolutionary multilevel TT framework describes the dynamics of change and interaction within each level as well as the interactions and change across levels, structuring activities in local practices (Geels, 2005). There are no specific rules that constrain activities at the niches level, and actors can move in many directions, and have to make much efforts in articulating and upholding rules. At the sociotechnical regimes level, there are existing rules that serve to coordinate the activities of different actors in their regular practices, and are thus difficult to change. Sociotechnical landscapes provide the strongest structuration for the activities of different actors, as these comprise the material environment, prevalent cultural beliefs, values and symbols at the broad societal level. Geels (2005) proposes that these three levels are hierarchically nested, multiple niches embedded within regimes, and multiple regimes within the same landscape. For novelties to gain adoption beyond their originating niches often encounter mismatches with existing regimes, making their breakthroughs difficult. For technological innovations to bring about system level innovations, or TTs, changes in many connected regimes need to take place to bring about changes at the landscape level. There are different sociotechnical regimes, such as technological, policy and sociocultural. Each of these regimes has its own internal dynamics as well as interact with each other. If the internal developments across regimes do not align, tensions develop, leading to weakening of the linkages, which may provide a window of opportunity for radical innovations to breakthrough from their niches. The establishment of a new sociotechnical regime often requires a diverse set of transformations in infrastructures, practices, policies and organizations.

Research context and questions

This paper studies the evolution of a joint school network of special education needs (SEN) schools whose history dates back to 2003. The first author met this network in 2011, in the context of

a contract evaluation research commissioned by the Education Bureau (EDB) of the Hong Kong SAR Government to evaluate the 21 EDB-funded e-learning pilot projects. The EDB launched the 3-year e-learning Pilot Scheme (2011–14) in order to develop, try out and evaluate when and how e-learning works best to bring about effective interactive learning, self-directed learning, and to cater for learner diversity in different curriculum and school contexts in Hong Kong (EDB, 2011; Law, 2013). After the evaluation study (referred to as Study 1) ended, four of the most successful pilot projects was selected for a follow-up study (Study 2, 2014–16) to investigate the sustainability and scalability of these projects after the funding period ended.

Study 1 findings show that the e-learning technology developed in some of the projects was marginally used even during the 3-year pilot period. Analysis of Study 2 data shows that while the e-learning technology developed may still be used by one or two schools in some of the projects, all of the project networks stopped functioning after the project funding ended, except for one of the projects—Project S. The 10 schools in Project S continued to fund further technology development from their regular school budgets, and both the scale of adoption and level of pedagogical transformation taking place in the schools actually progressed exponentially during Study 2. In-depth analysis of the Project S data collected during Study 1 and Study 2 regarding student and teacher learning was reported in Law, Liang and Cheng (2017). The children in the 10 schools had various forms of intellectual disability, and some may have in addition physical disabilities. It is important to note here that there is great diversity among the 10 schools in terms of the age of the children. Some take in primary school age children, some secondary, and some both primary and secondary.

An opportunistic study using data generated from an innovation network spanning 11 years

In the process of interviewing the Project S principals and project team members during Study 2, the research team gathered that the schools in the Project had already been collaborating as a joint school network (Network S), since 2006, initiated by the principals. Both the project team leaders and teachers attributed the success of Project S to the history of collaboration in this Network. Unlike the other project networks in the Scheme, which were all established for the express purpose of bidding for an e-learning pilot project, the schools in the Project S had already successfully collaborated in three consecutive joint projects since the establishment of the Network and before they worked together on the e-learning pilot project. Network S thus potentially offer empirical historical data for an in-depth case study on sociotechnical evolution in the implementation of e-learning innovations, which is the focus of the present paper.

Research questions

According to the sociotechnical change model (Geels, 2002), social practices brought about by technological innovations take place at the niche level, but for these to be sustained and scaled require concomitant changes at the regime and landscape levels. Project S showed the best evidence for scalability among the 21 e-learning projects supported by the government. In this paper, we report on a more focused study on Network S from 2006 to 2016 to identify if there is evidence that its work has brought about regime level changes, and if so, to examine the features and conditions that impact on regime level factors. Our specific research questions are as follows:

RQ1: How many phases of development can be distinguished based on the innovation foci of the Network?
RQ2: Which are the factors that were critical in determining the innovation focus and its success in each phase of development? Which of these factors belong to the niches and landscape levels?
RQ3: What architectures for learning were established during each phase, ie, what organizational structures, interaction and decision-making mechanisms were established to lead change and support aligned learning at different levels across the Network?

RQ4: What are the interactions between the technological developments undertaken and the social practices promoted in each phase? Is there evidence that the innovation influences regime-level factors?

RQ5: What are the factors that contributed to the successful transitions through the different phases of the Network's development? What insight, if any, does the sociotechnical change analysis shed on the scalability of technology-enhanced learning innovations?

Research design and methodology

Case study design and data collection

The present study is a longitudinal case study of Network S. While there were data collected from surveys, interviews, lesson observations and learning artefacts created by the students during the course of Studies 1 and 2 for Project S, the data used in this analysis were collected expressly for addressing the specific research questions listed above. We are very grateful to the Project and Network leaders for their generosity in making available at our request two sets of documents for the purpose of our research: (1) the entire set of monthly Network principal meeting minutes and (2) meeting notes and related documents of the project coordination team. These became a primary source of data for the present study, providing us with a historical archive that allows us to understand how the Network goals and purposes, perceived tension, and architecture for learning evolved over time, and how the architecture impacted on the innovation development and changes in teachers' practices. Additional interviews were conducted with the key members of Network S and the project coordination team, as well as the retired academic from the UK who had been serving as a consultant for Network S since its establishment.

Method for analysing sociotechnical change over time

The first analytical task was to identify the different phases of development in the history of Network S into phases by identifying the different innovation focus for the Network over time. This was accomplished through analysing the interview transcript with the Network leaders, and triangulated through a content analysis of the Network S meeting minutes. As shown in Figure 2, six phases were identified.

Next, we separated the meeting minutes into six periods according to the phases they belong to. These were then systematically coded using N-Vivo to identify for each phase:

- The reasons for selecting the innovation focus;
- The resources available for the innovation and their sources;
- The challenges encountered in the innovation process and how these were resolved;
- The organizational structures, membership, interaction and decision-making mechanisms involved in the innovation process.

After the coding of the meeting minutes, we coded the interview transcripts according to these same categories to enrich as well as triangulate the results for the six phases. The key findings from this analysis were used to answer research questions 2 and 3, and are summarized in Figure 2. The other two research questions were further explored based on the findings from the first three research questions.

Findings

Six phases of innovation development foci

There was strong consistency based on the analysis of the interview transcripts and the meeting minutes on the progressive changes in the innovation foci over the 11 years of the Network's history. As shown in Figure 2, the Network first embarked on developing a set of SEN curriculum

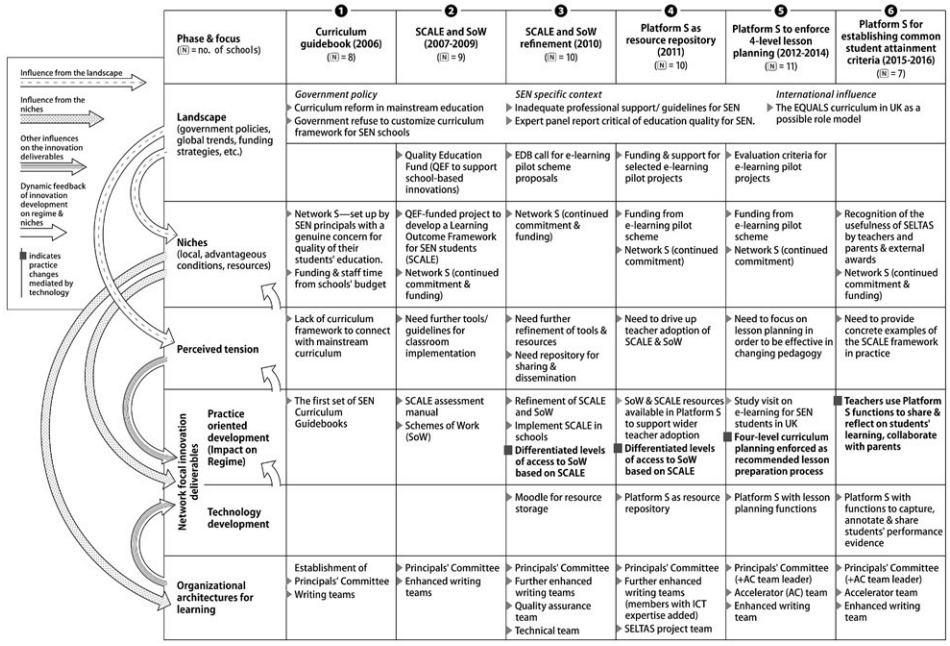

Figure 2: A summary of the sociotechnical evolutionary trajectory of Network S over the six phases from 2006 to 2016

guides for key school subjects. In phase 2, the Network focused on two developments: (1) an assessment manual (SCALE) to serve as a guide to help teachers to detect students' learning improvement by providing finer grain descriptors of achievement and (2) Schemes of Work (SoW) that provide outlines for each of the key subject areas on how to implement the different parts of the mainstream curriculum to cater for different special education needs. Hence, during these two phases, the key foci were to develop a common, operationalizable guide for curriculum implementation and assessment for teachers in the Network.

In phase 3, ongoing refinement was made to the SCALE and SoW documents. Because of the diversity in terms of student profile across the 10 schools, two levels of SoWs were deemed necessary. At the Network level, SoWs are developed for different topics by taking into consideration SEN challenges and issues. Based on this, schools could further develop more specific school-based SoWs for their own use. Another focus during this phase was on improving teachers' access to these documents through setting up a digital repository for easy and guided access by teachers to these two kinds of curriculum resources. During this phase, the open source Learning Management System, Moodle, was repurposed to serve this purpose so that teachers can easily locate the SoW resources based on their students' abilities according to the SCALE manual.

In phase 4, the 1st year of the e-learning pilot Project S, the focus was to drive up teacher access and use of SCALE and SoW resources by developing from scratch a new technology platform, Platform S (nickname of the purpose-built technology platform, for anonymization purpose), to replace the Moodle platform which was found to be rather un-user-friendly by teachers. At the end of phase 4, there was greater adoption of the curriculum resources on Platform S because of its ease of use. However, the project leaders found that this did not make the teachers' pedagogical practices more student-centred. While teachers liked to use the resources in the repository, they

did not really understand the pedagogical assumptions or targeted learning outcome levels that guided the design of the specific resources. The project leaders realized that without a deeper level of understanding about how student-centred learning can be implemented for SEN students, having access to quality curriculum resources would not bring about the pedagogical changes targeted. Hence, in phase 5, the Network organized a study visit to the UK on e-learning for SEN students for key implementation teachers in the 10 schools, with support from their project consultant from the UK, to provide the necessary pedagogical input to the project leaders and teachers. During this phase, lesson planning functions were also added to Platform S so that teachers need to go through a *guided decision-making process* in order to access the curriculum resources for use with their students. Platform S guides teachers through a four-level lesson planning process by following this sequence:

1. Planning starts with selecting the curriculum component within the general curriculum guide that the lesson is related;
2. Choose the Network-level SoW for the specific topic they plan to teach;
3. Select the school-based SoW customized to suit the needs of particular groups/classes;
4. Select the target class to be taught. The system will suggest learning activities and associated resources stored in Platform S suitable for the competence level of specific students as recorded on the system database using the SCALE instrument.

Teachers would not be able to access the curriculum resources they wanted to select and use unless they follow this four-step process.

In phase 6, Platform S was extended from a web-based platform to provide mobile applications, making it more convenient for teachers to collect evidence of students' formative performance. More collaborative functions were also added, such as providing parental access to students' learning records, allowing students to upload their own assignments, etc. The change was further consolidated through adding platform functions that support collaboration with parents as partners in facilitating children's learning. Through these new features, teachers were able to record the assessment results of individual students using multimedia recording of students' performance. These assessment records serve to help teachers in their further lesson planning as well as to provide feedback to students and their parents on the children's learning progress.

It should be noted that technology deployment was included as an innovation goal only from phase 3 (2010), 1 year before the start of the e-learning pilot. Throughout the 11 years of the Network's history, the driving focus of concern has never been on technology use or development per se, but how to promote and support teachers in their adoption of more student-centred pedagogy and assessment. Digital technology became relevant in the context of enhancing students' digital literacy skills and for providing customized feedback (to students and their parents) for better learning outcomes.

Another important observation from this analysis is that due to the strong innovation focus on changing teachers' practices, the innovation impacted on the regime-level relationships within this Network of schools, ie, the rules and relationships among the practices of teachers and students, technology, infrastructure, and the professional culture in schools. This is further elaborated in the discussion section.

Factors that were critical in determining the innovation focus and its success in each phase

Our analysis of the data show that the factors that determine the innovation focus for each of the phases can be categorized into three groups: the focal problem or tension as perceived by

the project leaders, the resources available and the Network S architecture for learning (AfL). The perceived tensions, which were analysed and reported above, determine the nature of the innovation foci over time, the resources available determine the magnitude and sophistication of the deliverables targeted, while the AfL plays a crucial leadership and administration role in realizing the innovation vision and mission.

Resources (niches) for change and innovation

The tangible resources used by the Network to support the innovation development in each phase are listed under niches in Figure 2. The resources (both financial and human) committed by the schools in the Network are relatively modest, but have been critical in ensuring that core services and priority development would not need to be disrupted even when external funding is not yet available, as in phases 1, 3 and 6. On the other hand, the development of the core curriculum documents (SCALE and SoWs) as well as Platform S and its many functions and features would not have been possible without the resources provided by the different funding schemes made available by the EDB to support strategic implementation of the government's education policy. Hence, the niches available to the Network are closely connected to the Landscape-level factors.

Leadership for change and innovation: Organizational architectures for learning

As Wenger (1998) points out, informal groups and interactions may also play important roles as integral parts of the architecture for learning in a community of practice. Our data sources related to the Network's AfL are limited to formal Network documents and interviews. Hence, we have restricted our analysis to only formally established structures and mechanisms. The findings regarding organizational architectures summarized in Figure 2 show that these were changing over the different phases, and became stabilized only for the transition from phase 5 to 6. However, there was one important feature that remained constant throughout the 11 years of the Network's history—the leadership role played by the principals through the Principals' Committee (PC), which met on a monthly basis. The core concern of the PC was to identify strategical development goals, mobilize resources and establish requisite working teams to execute the necessary detailed planning and actions. The PC was also responsible for making important decisions regarding the provision of professional learning and support to teachers at the Network level, seeking advice from the UK consultant and consultants from a local university.

Before describing the detail architectures for learning in the Network, it is important to reiterate that the Network was established to realize a common vision shared among the principals: that the SEN children they serve should have opportunities to achieve the same educational outcomes specified in the mainstream school curriculum through suitably designed learning activities and resources. The Network refers to their pedagogical ideal as the SAME approach, short for Systematic Approach to Mainstream Education.

Phase 1

In this Phase, the PC established a number of "Writing Teams" (WTs), one for each Key Learning Area (KLA) in the mainstream curriculum, to take responsibility for writing the respective customized curriculum guides by adopting the SAME approach. Each WT comprised several specialist subject teachers selected from the Network schools, coordinated by an Organizing Manager (OM, usually a specialist teacher from one of the schools) and a Strategic Manager (SM, usually one of the principals whose expertise was in that particular subject). Since the SM in each of the WTs was one of the principals in this Network, the PC was able to have a good understanding of the work in this phase without setting up any formal monitoring mechanism between the PC

and the WTs. It was reported that each team spent about 2 weeks on writing up the curriculum guide for the Network.

Phase 2

In this phase, there was no fundamental change in the organizational structures. With funding from the Hong Kong Quality Education Fund (QEF), the network was able to engage more experienced teams in the WTs. Each WT contributed to the development of a manual for the KLA it took responsibility for, which elaborates the SAME assessment approach, and tasks that can be used to assess students' learning outcomes based on the graded attainment scales and level descriptors developed in Phase 1. The assessment tasks in the SCALE documentation was piloted in the Network schools during phase 2 for the assessment of students. Hence, more teachers were involved in this phase of the project, bringing some impact on the assessment practice of a small number of teachers.

Phase 3

Outcomes from phase 2 confirmed their belief that the SAME approach was the right direction to go. The WTs continued to refine the previously developed resource materials and further promoted the use of SCALE in the Network schools. In this 1-year unfunded period, the PC worked on developing an e-learning pilot project proposal to submit to the EDB. Two more organizational structures were established. To facilitate online access of the resources by teachers, a Technical Team was established to set up the Moodle platform mentioned earlier. With the establishment of the Moodle platform, more teachers voluntarily contribute their own resources to the pool. The PC was concerned about the quality of the resource materials in the repository, and a Quality Assurance Team was set up to monitor the quality of the materials uploaded to the Moodle repository. Members of the Quality Assurance Team were experienced principals in particular KLAs with the authority to revise the materials as necessary.

Phase 4

This was the 1st year of Project S. While a main task was to design and build the new Platform S from scratch, the project was not considered as simply a technical one. The Technical Team established in phase 3 was considered inadequate for taking on the project and was disbanded. The WTs were further strengthened by adding in teachers with ICT expertise. In addition, a Project Team was set up, led by the principal who was also the Project Coordinator accountable to the EDB for the entire e-learning project. Other Project Team members included teachers from the different schools familiar with the special needs in different schools in the Network. Two KLAs (Chinese language, and Personal Social and Health Education) were selected as foci for the first-stage planning and development of a system of resources for piloting in the Project. The Project Coordinator serving as the Project Team chair was thus the formal connection between the PC and the Project Team, reporting to the PC about project progress and contributing to the PC's deliberations regarding the Project.

Phase 5

As teachers began to use Platform S, different kinds of issues—technical, logistic, organizational as well as pedagogical—were reported. The Project Team did not have adequate knowledge and expertise to address the diverse problems that surfaced in the different school contexts. To address these new challenges, the Project Team was replaced by a new organizational structure called the "Accelerator Team" (AC Team), which comprised senior teachers who have knowledge in both technology and pedagogy from each of the Network schools to serve both technology development and pedagogical implementation functions. To support quality pedagogical implementation, the AC Team organized provisions of on-site support to teachers in the form of peer coaching and school-based training workshops. It also solicited feedback, critiques and

suggestions from teachers, and worked with the software development vendor to decide on the necessary modifications and developments regarding features, functions and interface designs of Platform S. The chair of the AC Team, who was the senior teacher taking key responsibility for liaising with the software development company contracted for the Platform development, became a co-opted member of the Principals Team. Thus the AC Team chair, who actually was a senior teacher in the school headed by the Project Coordinator, replaced his principal to serve as a bridge between the PC and the AC Team. This change had the advantage that the AC Team chair, as a middle manager and a teacher, had a much better understanding of how the project was implemented on the ground in each of the schools, and was more able to communicate the problems and challenges as perceived by teachers more clearly to the Network leadership. Also, being involved in the PC deliberations, the AC Team chair was able to communicate and implement the PC decisions more effectively in the context of Project S.

Other than the position and role of the AC Team chair, the fact that the membership on the AC Team were senior teachers with curriculum/leadership roles in the respective project schools also contributed much to the team's ability to "accelerate" adoption of e-learning to foster SAME approach pedagogy through using Platform S. All AC Team members carry a primary responsibility to encourage and support the e-learning implementation in their own schools. This means that the AC Team members had a very clear understanding of the Project implementation status and challenges encountered in the different schools. They worked directly with the classroom teachers during the implementation process and learned from each other's implementation efforts. The AC Team played a crucial role in the successful implementation and scaling of Project S.

Phase 6

This was the first 2 years after the end of the Project S funding period. The momentum for the teachers to make use of Platform S to design personalized learning activities for students was already established. The Network determined to continue the trajectory of pedagogical innovation that was started for almost a decade. As described earlier, further technical development of Platform S as well as pedagogical support for scaling up the innovation implementation in classrooms continued despite the absence of external funding. The formal structures that were in place in phase 5—the PC, AC Team and the enhanced writing teams continued to function in the leadership and implementation of e-learning innovations under the SAME approach using Platform S.

Summary and discussions: The sociotechnical evolutionary trajectory of Network S

In this final section, we reflect on our findings in this study to address RQ5—how do the factors at different levels of the sociotechnical system contribute to the successful transitions of Network S through its pedagogical innovation journey? Through this reflection, we also explore the utility of the sociotechnical transformation theory in helping us to understand the sustainability and scalability of technology-enhanced pedagogical innovations.

Our analysis shows that for each of the six phases in the developmental trajectory of Network S, there is a consistent pattern of interaction dynamics across the different levels of the sociotechnical system. While the core Network actors play a crucial role in formulating and driving the innovation in each phase, a large part of the resources (niches) needed for the innovation came from the government, which is part of the overall societal landscape. Thus, the Network actors had to sensitively leverage the landscape-level factors to secure the niches needed for their work.

Project S was successful in developing technology tools and resources that were adopted by teachers and helped to bring about changes in their practice. It is clear from the innovation trajectory that the years of innovation carried out in the Network from 2006 to 2010 that did not

involve any technology use or development was crucial for the success of the e-learning pilot project. In fact, the artefacts developed during these years laid the foundation for guiding the regime-level changes in the schools. It can be said that the major efforts throughout the 11 years of the innovation trajectory were focused on regime changes, within the confines of the Network. Technology innovation is only one element in the complex web of interdependent changes at landscape, regime and niche levels.

An important role of the technology in Project S is its role in enforcing/structuring the teachers' lesson planning practice from direct access of teaching and learning resources to a four-step decision-making approach in the selection process. Platform S served to institutionalize a regulatory rule—using technology to make impact at the regime level. This is seldom discussed or reported in the e-learning research literature, but clearly played an important role in the success of the project in changing teachers' pedagogical practice. In fact, the design of e-learning tools and resources, such as the learning management systems, social media platforms, student e-portfolios, etc plays an important role in structuring our day-to-day learning and teaching practices, thereby changing our implicit understanding of the nature of these processes. e-Learning technology designs should pay attention to the regime (practice) implications to foster alignment with relevant pedagogical theories.

While Project S was the only one out of the 21 funded e-learning pilot projects that was able to sustain and scale past the funding period, the innovations and their positive impact have not propagated beyond the regime-level changes within the Network. While Network S being pragmatic and opportunistic in crafting innovation projects for funding from government sources to realize their vision, such an approach is precarious in its outcome, and the continuity of the niches for continued innovation is lacking. Without making impact on the regime and landscape levels, the e-learning innovations pioneered by this Network is still fragile, and is a classic case of innovations that are prone to failing in sustainability and scalability (Geels, 2002). In fact, this fragility is evidenced by the fact that only seven schools remained in the network in phase 6. Of the principals who started the Network in 2006, many have already retired at this point. Some of their successors did not share the same history and commitment, and stopped their membership in the Network S.

Finally, analysis from the sociotechnical evolution perspective reveals the important roles played by the socio-organizational structures and interactions associated with the innovations. Just as technological artefacts undergo an iterative process of change and refinement in the innovation, the architecture for learning (Stein & Coburn, 2008) also needs to change and evolve as the tensions unfold and change during the course of the innovation trajectory. Our analysis shows that the organizational structures changed from one phase to another to bring in the relevant stakeholders and expertise for the innovation. Achieving alignment across different levels of the education system (classrooms, schools, networks, districts, etc) during the process of innovation and change has been recognized as important for the scalability of innovations (Law, Liang, & Lee, 2016). The analysis of the architecture for learning established by Network S over the different phases of innovation shows that during each phase, the alignment across schools at the leadership level was achieved by the PC comprising all principals in the Network. Alignment across school leadership and the teachers was achieved through having membership that is common between the PC and the innovation implementation teams. The AC Team appears to have a particularly advantageous composition in that the members were senior teachers tasked to lead the innovation implementation in their own schools. The Team members together made day-to-day decisions for the Platform S development and Project implementation. Having the chair of the AC Team co-opted as a member of the PC also ensures that the Project Team has a voice at the

top level of leadership in the Network. This is different from having a member of the PC chairing the Project Team, in which case the link person serves as a voice from the leadership team to the Project Team.

In summary, this study shows that the sociotechnical change model helps us to gain a deeper understanding of the factors influencing the scalability of technology-enhanced pedagogical innovations from a broader, societal level. Given the increasing presence and importance of technology use in learning and teaching, the adoption of a sociotechnical perspective in the study of e-learning innovations helps us to gain a better understanding of the long-term impact of technology on learning and teaching as a social practice. We hope that such studies will contribute to the design of principles for design-based implementation studies (Fishman *et al.*, 2013) to enhance their scalability.

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Statements on open data, ethics and conflict of interest

Our data are not open to public and there are no conflicts of interest. Our study follows all recommended ethical guidelines for non-clinical research involving human participants. The research protocol was approved by the Human Research Ethics Committee for Non-Clinical Faculties of the University of Hong Kong before data collection started (Ref. No: EA 601111& EA 100214).

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