Designing Multilevel Architecture for Learning to Support Continuous Learning Innovations: Two School Cases in a Design-Based Implementation Research Project

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Abstract: In Design-based implementation research (DBIR), the focus of design efforts is on not only the creation of tools and resources for student learning improvement, but also the (re)design of institutional conditions that support the improvement to be sustainable and scalable. This paper reports on a DBIR project in Hong Kong supporting teachers to use self-directed learning approach in STEM education. In crafting conditions for the project implementation, one of the design principles is building multilevel architecture for learning to strengthen school leaders and teachers' capacity to be self-organized in the long term. In-depth case studies on two schools participating in the project shows feedback loops play a key role in the self-organized learning of teachers and school principals. Teachers as brokers could facilitate the spread of innovative practice. Implications to design principles at the institutional level are discussed.

Introduction

Sustaining and scaling up learning innovations (Coburn, Russell, Kaufman, & Stein, 2012; Clarke & Dede, 2009; Looi & Teh, 2015) challenges design studies (aka, design experiment or design-based research). In design studies, learning scientists have worked in real classroom settings to design, develop and test new forms of learning strategies, tools and resources in order to bring out new possibilities of education improvement (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The growth and flourish of learning innovations rely much on supportive conditions beyond classrooms, such as professional input from researchers and external funding, which however are difficult to maintain when the design studies end. Learning scientists remind us that design studies should go beyond determining "what intervention works to improve learning" to examining and design the institutional conditions to help the innovations to be sustained on their own (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013; Penuel, 2019). Design-based implementation research (DBIR) (Fishman et al., 2013) is an emerging approach to sustain and scale up learning innovations. It makes efforts to design the institutional conditions where the learning innovations take place.

DBIR emphasizes the importance of building up educational infrastructure (Hopkins, Spillane, Jakopovic, & Heaton, 2013; Spillane, Hopkins, & Sweet, 2017; Penuel, 2019). Educational infrastructure refers to the formal organizational structure, routines and resources intended to support teachers' new forms of instructional practice and enable them to improve that practice (Spillane et al., 2017). It can be about curriculum materials, instructional techniques and routines, roles and instructional leadership (Spillane et al., 2017; Penuel, 2019). The process of (re) designing educational infrastructure that influence classroom activities is referred to as infrastructuring (Penuel, 2019), which can be supported by research-practice partnership (RPP). Researchers establish long-term collaboration with practitioners, and build practitioners' capacity for sustaining innovations by engaging them in iterative problem-solving process for problems of practice (Coburn & Penuel, 2016).

Though Fishman et al. (2013) have contributed overarching design principles for DBIR, few studies have researched on how specific design principles worked for their DBIR projects. Similar to design experiments which study the process of student learning, DBIR also requires the examination of the process that schools (re)design their institutional conditions guided by particular design principles. It helps develop researchers' knowledge and theories about building the capacity of the organization to implement, sustain and scale up the innovation that supports continuous improvement on student learning (Penuel, 2019).

This paper reports on a DBIR project that aims to support teachers to use self-directed learning (SDL) approach to teach STEM subjects (SDL-STEM practice for short). In this project, we provide participating schools with a conceptual design principle named "multilevel architecture for learning (AfL)" to guide the design of institutional conditions that support the project implementation. Based on this principle, schools (re)constructed a set of educational infrastructures that facilitate the engagement of actors from different levels of the education system, including teachers, school middle management, school principals and researchers.

Altogether 20 primary schools and 12 secondary schools were involved in the project. After the end of the project, great diversities were observed across the schools in terms of teachers' SDL-STEM classroom practices. We are curious about why some schools can scale SDL-STEM practice extensively within the 19-month project period, while others struggle. We have the following two research questions:

- RQ1: How do schools build up their multilevel AfL guided by the design principle?
- RQ2: How do the multilevel AfL facilitate the implementation of SDL-STEM practices?

In the following sections, we will elaborate on the design principles of constructing multilevel AfL in schools for the project implementation.

The design principle: Multilevel Architecture for Learning (AfL)

The DBIR project, which we refer to as STEM project in this paper, aims to provide support to teachers for developing their capacity to adopt self-directed learning (SDL) as a strategy to promote STEM education. This is a 19-month University-School Support Program (2017-2019) funded by the Hong Kong Education Bureau. The design foci of this project are twofold: design interventions at both classroom and institutional levels. At the classroom level, the support of the project included: (1) theme-based workshops introducing SDL as well as advanced STEM-related topics (e.g. using virtual reality tools for scientific exploration), and (2) on-site school-based collaboration design activities (Voogt et al., 2015) and lesson observation in which we assigned project consultants to support teachers to design, implement and evaluate the classroom implementations.

The design intervention at the institutional level is the focus of this paper. Instead of (re)designing institutional conditions by negotiating with practitioners directly (c.f., Spillane et al., 2017; Penuel, 2019), we provided a conceptual guidance to the schools with the aim of "building multilevel architecture for learning to strengthen school leaders and teachers' capacity in the long term". We introduced this idea in a workshop targeting school leaders. The following section elaborates on this design principle.

For the participating schools to sustain and enhance the momentum for learning innovations, the school itself needs to develop its own capacity to be self-directed and self-organizing in the longer term. As discussed in the education reform literatures (e.g., Stein & Coburn, 2008), the challenge to sustaining and scaling up learning innovations is fundamentally the learning at multiple levels. Sustained changes in classroom practice require aligned changes to take place within the education system from classroom to school, district and system levels (Davis, Eickelmann, & Zaka, 2013; Law, Niederhauser, Christensen, & Shear, 2016). Law et al (2016) propose a multilevel and multiscale learning (MLMS) framework to conceptualize the interdependence of learning taking place at different levels of the education system. Specifically, at the teacher level, teachers need to learn and change their beliefs, pedagogical knowledge and practices to create innovative learning conditions for students. Schools need to provide adequate opportunities and supportive conditions for teacher professional learning. The changes in school conditions are regarded as the learning outcomes at the school level, such as school ICT infrastructure, vision and innovation plans, staff appraisal, and timetabling etc.

The MLMS framework is also grounded on a theory of collaborative inquiry and knowledge building. For effective learning to achieve multilevel change, peer learning needs to take place at multiple levels. For the higher levels of learning (e.g., project network level, district/system level), the innovation needs to be implemented at a larger scale to ensure that actors at high levels of the system would still be able to learn from their peers. Therefore, innovation networks have been found to be a productive model of supporting different levels of learning for innovation.

Architecture for learning (AfL) is needed for actors at multiple levels to socially construct the knowledge about the implementation and facilitate alignment of learning. Law, Yuen and Lee (2015) broadly define AfL as "organizational structures, mechanisms and artifacts that are available to facilitate interactions and consolidate change at different levels of the education system" (p.3). They further point out there are four important elements in the AfL for innovation: (1) Organizational structures that direct and guide interactions; (2) Mechanisms for sharing, interactions and decision-making; (3) Artifacts that serve as reifications of outcomes of interactions to propagate decisions and advances in understanding; and (4) Technology that support communications, interactions and knowledge management of individuals and communities.

Given the design principle of "multilevel architecture for learning", we recommended school principals to form a team involving participants at multiple levels, engaging subject teachers, school middle management, school principals, technical support staff, etc. The multilevel leadership will contribute importantly to building up school-based implementation strategies and creating necessary conditions to sustain innovations, including physical and digital infrastructure, staffing and human resource allocation and development strategies, organizational structures, school routines, decision making mechanisms, appraisal system, timetabling, etc. For the interaction mechanism, there should be school-based co-planning of the curriculum units, lesson observations and facilitated debriefing of the observed lessons. School leaders were advised to attend lesson observations so that they can get the opportunity to learn about the SDL-STEM practices and gain some understanding about leadership and school-level practices within the school.

Our research team also creates several AfL mechanisms to facilitate learning at various levels among participating schools. For example, at the teacher level, professional development workshops were held for teachers to address SDL-STEM issues and topics. These meetings provide opportunities for teachers within the project network to share experiences around their everyday practices, such as the design of curriculum units, learning and/or assessment tasks, choice and deployment of learning resources/tools. We also encouraged participating school to run open classroom observations. Project teachers and principals can participate in any of the open classrooms. This is an important mechanism for in-depth inter-school peer learning. At the school leadership level, we encouraged the principals of the participating schools to join the school cluster meetings described above so that they have opportunities to learn about the SDL-STEM practices in other schools, especially on leadership and school-level practices.

Methodology

Case study

This study is interested in understanding how schools harnessed the multilevel AfL design principles of the STEM project to scale-up innovative practice. It focuses more on understanding the process of how the school reacted to the design principles promoted by the researchers to strategically craft AfL in their local context, rather than simply demonstrating the utility of the design principles. Case study is an appropriate research method to provide holistic views on the developmental trajectory of how schools (re)constructed multilevel AfL to influence the SDL-STEM implementation over time. We purposively selected project schools, which have successfully implemented the SDL-STEM practices and indicated future plans to sustain and scale up such practices. Thus, this study will provide implications to how instructional improvement can be sustained with the DBIR approach and research-practice partnership.

The criteria of successful implementation are based on the findings from the school evaluation our research team conducted at the end of the project. The school evaluation includes the evidence-based snapshots on teachers' SDL-STEM practices. As a requirement of the project, teachers of each school should design and implement at least three STEM-related lessons during the project period. To evaluate the degree to which teachers used the SDL-STEM approach, we observed each classroom implementation. Research team members took ethnographic field notes and completed a structured analysis. The structured analysis included an evaluation about teachers' performance on the five autonomous processes of SDL (Hew, et al., 2016), and a summary of learning elements from different STEM disciplines exhibited in the classroom practice.

Given the space constraint, we purposively selected two project schools (School A and B) with different backgrounds so as to ensure the diversity of school contexts. Both School A and B have decided to continue the SDL-STEM practice by joining the extension of STEM project for another two years (2019-2021).

School A is a government-funded secondary school whose students are generally low academic achievers located in a low SES neighborhood. However, the strength of the school is the strong connection with the local communities. For example, the school has joined a school-community partnership scheme called Elder Academy. Through the scheme, the students have opportunities to apply their knowledge and skills to promote physical and mental well-being of the elders in the local community. Before joining STEM, School A has SDL experience through a university-school partnership project with another institution in Hong Kong. However, in that project, the SDL pre-class planning activity had a sharply different theoretical underpinning from our project. After the previous collaboration ended, the school principal decided to join our project and embraced our approach to SDL.

In contrast, School B has a more aligned SDL approach with STEM. School B is a government-granted primary school that has collaborated with our research team even before joining the SDL-STEM project. The school had joined us for a previous government-funded university-school partnership project a year earlier to promote SDL in Science, which shared the same SDL approach with the STEM project in this study. In that previous project, the school started learning how to design science lessons with SDL approach with a team of General Studies (GS) teachers.

Data collection

The study is designed to compare the similarities and differences between the development trajectories of two schools in reconstructing multilevel AfL to influence the SDL-STEM implementation over time. To uncover the change of the components during the project period, we used interviews with the school principals and participating teachers to examine the components of each school's AfL. In particular, the teacher interviews were conducted in the form of focus group interviews involving around 4 to 5 key teacher members in the project. Interviews were conducted at three time points: at the beginning, in the middle (after the first or second classroom implementations), and towards the end of the project. All interviews took 45 minutes to 1 hour. Interviewees were asked to identify the components of the multilevel AfL in their school as well as how and why their AfL changed over time during the project implementation.

We also need to understand the influence of AfL on the SDL-STEM implementation, in particular, how the change of AfL relates to the change of SDL-STEM implementation, if there is any. Evidence was collected through interviews. During the teacher interviews, participants were also asked about how they interacted within the AfL, what decisions had been made during those interactions, and how such decisions influence their classroom practices.

To complement the interview data, we drew upon teachers' reflections in the debriefing sessions held after each classroom observation of STEM implementation. Teachers would reflect on their curriculum and pedagogical design ideas, the actual classroom implementation and possible improvements. The debriefing sessions ranged from 30 to 45 minutes and were audio recorded and transcribed for analysis. Strategic development plan of each schools and project documentations on teachers' participation in the project activities were also used to complement the interview data.

Data analysis

We employed a case study methodology (Yin, 2008) to compare and contrast the two schools' AfL for SDL-STEM implementation. The school was our unit of analysis. We began by analyzing transcript of interviews and discussions during debriefing sessions. We conducted two rounds of coding, the first of which focused on the four AfL components (organizational structure, interaction mechanism, artefacts, and technology). After this round of coding, we created summary matrices to compare similarities and differences between the schools across the AfL components. We also examined the changes in the AfL components at three time points: at the beginning, middle and at the end of the project. Then we further explored the reason why AfL changed and what is the impact of on the project implementation. Therefore, we conducted a second round of open coding on the transcript of the interviews/teacher debriefing notes to explore the rationale of the change and impact on teacher practices. Then we created other summary matrices and conducted a series of queries to examine the relationship between the reasons of change and the impact on teachers.

Findings

In this section, we start with reporting the overview of SDL-STEM implementation in the two schools during the project period. A total of three STEM curriculum cycles were implemented in each school, and presumably one cycle in one semester. However, the scales of implementation are different. In School A, the implementation started with a pilot in two less competitive classes of Secondary One led primarily by a math teacher. In the second and third implementations, the school deliberately rotated the led subject of the SDL-STEM projects (computer and science respectively). The scale of the implementation also grown from two classes to an entire Secondary One (five classes) by the end of the project. Compared to School A, the implementation of the SDL-STEM practice was in a larger scale in School B. For each implementation, the design of a STEM topic focused at one grade level and was led by different core team teachers. At the end of the project, STEM curriculum topics at three grade levels (Grade 4-6) were developed altogether.

Multilevel AfL established for the project implementation

In this section, we described the development trajectory of multilevel AfL establish for the project implementation in each school by highlighting the change of the four components of AfL: organizational structure, interaction mechanism, artifacts and technology. Then we compare the similarities and differences between two cases.

Multilevel AfL of School A

At the beginning of the project, School A formed a core team consisting of the principal, vice-principal, academic coordinator, project coordinator and 8 teachers of four subjects - Math, Design Technology, Science and Computer - as the organizational structure unit of its multilevel AfL. Each member of the core team played a unique role. The principal was responsible for steering the overall direction for the project, setting up structures and mechanisms to facilitate teacher learning and mobilizing the school's social network to support project implementations. Although the project coordinator's expertise was in humanities and not a STEM teacher, he has experience and connections in green education. His main role was to utilize the space and resources given by the school to coordinate meetings and forge collaborations for teachers of different subjects. Notably, no subject teacher had expertise in SDL-STEM practice at the beginning of the project. Thus, the project core team assigned the implementation task to a math teacher who just joined the school with relatively less teaching experience. He was willing to learn and pilot STEM projects and supported by our consultants and attended open classes offered at other schools.

The main interaction mechanism of the core team was the lesson co-planning meeting and lesson observations. Each implementation had a lead subject and a teacher in charge from the core team. Teachers of the core team participated in workshops, co-planning sessions and lesson observations as advised by the design principle of the project. These sessions allowed teachers to build up their understanding of the SDL-STEM practice and learn from our consultants and peers from other schools. Teachers outside the core team were welcomed to participate and contribute ideas at various internal mechanisms for cross-subject collaboration.

There was a change in structure with two other teachers from the core team took up the role of STEM project coordinator and implementer for the second implementation. The reason of shifting the agency to other core team teachers was that the school principal was very pleased with the achievement in the first implementation and wanted this improvement to be continued. He understood scalability and sustainability as giving opportunities to teachers of different subjects to take the lead in STEM implementation. Thus, he suggested the lead subject to be change constantly, so that more teachers can learn about the practices and provide students with more diverse learning experiences across subjects and contexts.

Another crucial change we observed in the organizational structure is the involvement of more subjects and external parties in the school's social network. Leveraging its networking with local communities, the school involved local parties such as the Elder Academy, Federation of Hong Kong Industries and alumni mentors. The objectives for the SDL-STEM project went beyond STEM teaching and learning to include nurturing entrepreneurship spirit and engaging students with different interests and strengths. The teaching and learning resources accumulated through the implementations, including lesson plans and student worksheets, served as artifacts to communicate and align learning within the core team and with future teacher implementers.

In the third implementation, the nature of AfL remained unchanged despite that the members involved in the core team increased. The collaboration with the local parties continued.

Multilevel AfL of School B

School B designed a project team as a new structural unit with teacher leaders of different specialization to be in line with the multilevel AfL. Similar to School A, the project core team of School B comprised of teachers of different hierarchical positions including academic leader (T1), project coordinator (T2) panel heads of GS (T2, T3, T4), mathematics (T5), computer studies and ICT (T6), and a teacher (T7) without any formal leader position. However, some of the core team members were more experienced in SDL than those in School A. Academic leader and the project coordinator had participated in the previous SDL project while other team teachers had heard about SDL through the sharing of the SDL project within the school. Leadership at multiple levels takes different responsibilities. The academic leader held responsible for informing the Principal about the project progress and offering administrative support such as timetabling. The GS panel head (T2) was the project coordinator, responsible for coordinating with subject panels of Maths (T5), GS (T3, T4) and ICT (T6). The subject panel heads held responsibility for coordinating with teacher implementers not in the team. As such, the project team as a contingent structural unit nested with other existing structural units (i.e. subject departments and administrative group).

The formation of interdisciplinary team generated interactions for inter-subject collaboration. When designing STEM lessons, subject panel heads were able to coordinate with each other curriculum content, matching with each other teaching schedule. The inter-subject collaboration has facilitated the learning of SDL across subjects and build curriculum leadership among teachers. School B engaged in interaction mechanisms as advised by the design principle of the project. The school principal and academic leader in the team facilitated project team teachers to attend regular monthly professional development for project network schools. For each implementation cycle, co-planning sessions, lesson observation and teacher debriefing sessions were in place.

The AfL in School B remains stable but influences different agents over time. In each implementation cycle, different team teachers took the lead and involves different teacher implementers who were not in the project team. The first implementation was structured at the grade 5 level, involving ICT, GS and Maths teachers at that level. The second implementation was structured at the grade 4 level with the project coordinator (T2) and other three team teachers (T3, T5, T7) teaching 4th graders took the lead for designing STEM lessons. The third implementation was at grade 6 level with project coordinator (T2) and another GS panel (T4) to take the lead. Cross-subject collaboration was facilitated by having different panel heads in the project team. They first made decision on what roles that different subjects (ICT, Maths and GS) could play and then panel heads in the team discussed learning design with their team members. In the process of scaling up the innovation from Grade 4 to 6, the project team as a contingent structural unit nested with other existing structural units (i.e. subject departments and administrative group). Teachers not in the team were also susceptible to the influence of SDL because of the nested structure of AfL in school.

The lesson designs, student worksheet and moodle courseroom were reification artifacts which were generated via co-planning sessions, enacted and revised by teacher implementers including those who was not in the teacher team. Though T1 was not a teacher implementer, with his position as an academic leader, he brought forward the SDL rubric which was a reification artifact used in the project network that all teachers attempted to use the rubric in examining the self-directedness of a lesson.

Similarities and differences of the development trajectory of AfL

The finding shows both schools established a core team that comprised of school leaders and teachers of different hierarchical positions, including school principals, project coordinator, subject panel heads and normal teachers. The core team members played different roles in the project implementation. School principals steered the overall direction and the project, set up school infrastructure and coordinate different members to provide support to teachers' classroom implementation. The multilevel AfL also scaffold teacher collaboration within and outside schools. In both schools, co-planning meeting and lesson observation are key interaction mechanisms to promote teachers' professional growth and facilitate successful implementation of SDL-STEM practice in classrooms.

However, with similar design principles to start with, the schools exhibited distinct development trajectories in their implementations. Due to a longer history of SDL implementation, School B were more experienced and confident to start the project in a broader scope with a more systematic approach. The AfL was well established in the beginning of the project and the developmental trajectory was well planned. Without significantly changing the AfL, more teachers take turns to take agency and engaged in the SDL-STEM practices. By contrast, School A had difficulties to start the innovation because of the short history of SDL and low competence of students. They decided to start from small and tried to connect more resources in the local communities to drive the project forward.

Influence of AfL on the project implementation

Although the developmental trajectories differed in both schools, the AfL established against the local school context helped participating teachers in both schools became more proficient in SDL-STEM practice throughout the project period. In this section, we will report how the similarities and differences of the AfL influence the project implementation in two schools.

Feedback loops generated from interactions of actors drove the project forward

Both schools established a core team involving school leaders and teachers, and organized co-planning meeting and lesson observation as key interaction mechanisms to help teachers design and implement SDL-STEM practices. With the support of AfL, project members received feedback from other actors strengthen their confidence and capacity of SDL-STEM practice. Feedback helps teachers and school leaders become self-directed learners who are able to intentionally refine the institutional conditions to address the emerging problems in the project implementation.

In School A, in the 1st implementation, the teacher mentioned that the open lesson he attended before designing the first implementation at another school enabled him to learn and reflect. As he designed his lesson, the feedback he received from non-participating teachers enabled him to work more closely with different subjects and enrich his lesson plans. The feedback offered by our project consultants also played an important role in inspiring teachers and the management with new ideas, helping the team to stay focused and summarizing key learnings for future improvement. The school's internal mechanisms further allowed sharing among teachers across subjects. For instance, through staff meetings, teachers involved in the STEM projects shared with other teachers their learning and teaching outcomes and engaged in discussions.

After the 1st implementation, the core team observed improved student performance on SDL-STEM and the core team, including the teacher of implementation and the principal, was also invited to share his implementation experience at our workshops with all project schools. The positive feedback they receive from both students and teachers at other schools enabled them to become more confident in SDL-STEM practice. Teachers have also mentioned in the interview that the process of implementation enabled them to recognize the potential of their students and their knowledge acquired across subjects and outside the formal curriculum. Hence, when designing the next in-class activities, they would give students more space to explore on their own and express their ideas, letting them to choose their design parameters, experimentation methods.

With the experience from the first implementation, the team was able to plan ahead for the second year to be integrated into curriculum more smoothly. The management provided administrative support, such as time allocation for co-planning and timetable rescheduling, making it easier for teachers of different subjects to collaborate. Through discussion and reflection, teachers went through a process from not knowing how to implement STEM to understanding the "key step", which is identifying one lead subject so that other subjects can follow and know how to contribute. The extent of collaboration has increased from involving only the STEM subjects to other subjects and partners to promote innovation collectively.

In the second implementation, not only the principal and teachers but also students increased their confidence in SDL-STEM practice. The school hosted a STEM day for students to conduct some fun activities related to STEM. Teachers were very happy with the arrangement as it indicates a certain degree of recognition for their good effort from the public. The school and teachers have also created various internal and external opportunities for students to present their products as learning outcomes, encouraging them continuous engagement with the STEM learning. These artifacts created by the students enabled learning to be visible for students, teachers and community partners.

In school B, there were emerging interaction mechanisms to let teacher implementers to evaluate and revise the lesson design. Teachers, as self-directed learners, were enabled to collect feedback from lesson observation and then had time to revise the lesson design. Teachers were aware that the feedback for their own implementation experience could contribute to the improvement of similar lessons in other classes. Based on teachers' good perception of the first implementation strategy, STEM lessons were maintained to spread discontinuously across weeks that teacher implementers were given time to collect feedback and revise their lesson. The principal arranged teachers to share practice to school board members. Teachers got recognition of their innovative by such arrangement.

The need for brokers bridging key parties to sustain and scale up the innovation

The important role of "broker" has been discussed in the educational change literature which conceptualizes the process of educational change is one community of practice (Wenger, 1998) influence another (Stein & Coburn, 2008). Broker is the people who interact in two different kinds of communities and connect different communities by bring artifacts from one community to another. In both cases, there were some key brokers in connecting different stakeholders in order to sustain and scale up the innovation. However, their role was different in each case due to the differences of AfL

In School A, the project coordinator served as the key person to connect the school with the community partner. The school had strong connections with external organizations. For example, being an Elder Academy enables students to have regularly interactions with the elderly. Industry experts and alumni were invited to mentor the students. These connections enabled a rich context and diverse support for the implementation of STEM projects. More importantly, the interactions with community partners created additional feedback loops for the students, the school leadership team and the teachers. Through showcasing student works and engaging constantly with a variety of community partners, learning is made visible to all. Students demonstrated strong evidence for self-directed learning. The Principal gained confidence in the practices and give more trust and support to the teachers. Teachers gained a sense of achievement and were motivated to build on this virtuous circle of STEM practice.

In School B, all team teachers played the role of brokers and transmitted new practice and ideas to teachers who were not in the team. Such transmission was supported by the project team structure which coordinated with other existing structural units (i.e. subject departments and administrative group), and various interaction mechanisms, such as PD workshops, co-planning meeting, lesson observation and school administrative meeting. Team teachers designed SDL-STEM lessons learnt in the workshop and then individual subject panel heads in the team coordinated with their subject members to discuss the lesson design at designated grade level. The lessons were distributed in a way that implementing teachers could observe each other's lessons and revise their plans after up-taking feedback in teacher debriefing or other informal mechanism. Non-implementers who taught at the same grade level or the same subject were also welcomed to observe these SDL-STEM lessons. Team teachers noticed these teachers had got more ideas about SDL via lesson observations. Team teachers also shared their reflection on their implementation experience in public events upon invitation.

Discussion and conclusion

This paper reports on a DBIR project where design principles for school-based STEM innovations, including the need for a multilevel leadership architecture, were provided to guide participating schools. We reported on two school cases that have created and re-designed their multilevel AfL to achieve sustainable project implementation. The findings demonstrate the utility of the multilevel AfL framework in facilitating teachers and school leaders' capacity building for sustainable and scalable innovations. The finding further shows that through appropriately designed network organizational structures and activity mechanisms, teachers and school leaders could conduct self-organized learning to build capacity that are necessary for successful and sustainable innovation within a school. This has strong implications for long term sustainability of DBIR projects. The second finding is that feedback plays a key role in the self-organized learning of teachers and school principals. This implies that multilevel AfL should built in productive feedback mechanisms that scaffold the peer learning and knowledge construction among different actors. The third finding is the need for appropriate brokers in the organizational structure to bridge different key parties. School leaders can designate brokers in the project core team to coordinate resources and manpower within a diverse school-based team and with external communities. The cases reported in this study demonstrate two different trajectories of multilevel AfL development, with both achieving success in the project. The findings imply that the same design principles can generate successful but different multilevel AfL arising from differences in school contexts.

References

Clarke, J., & Dede, C. (2009). Design for Scalability: A Case Study of the River City Curriculum. Journal of Science Education and Technology, 18(4), 353–365. doi:10.1007/s10956-009-9156.

Cobb, P. A., Confrey, J., diSessa, A. A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. Educational Researcher, 32(1), 9-13.

Coburn, C. E., & Penuel, W. R. (2016). Research–practice partnerships in education: Outcomes, dynamics, and open questions. Educational Researcher, 45(1), 48-54.

Coburn, C. E., Russell, J. L., Kaufman, J. H., & Stein, M. K. (2012). Supporting sustainability: Teachers' advice networks and ambitious instructional reform. American Journal of Education, 119(1), 137-182.

Davis, N., Eickelmann, B., & Zaka, P. (2013). Restructuring of educational systems in the digital age from a co - evolutionary perspective. Journal of Computer Assisted Learning, 29(5), 438-450.

Fishman, B. J., Penuel, W. R., Allen, A. R., Cheng, B. H., & Sabelli, N. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. National society for the study of education, 112(2), 136-156.

Hew, K. F., Law, N., Wan, J., Lee, Y., & Kwok, A. (2016). Self-directed learning in science education: Explicating the enabling factors. Singapore: International Society of the Learning Sciences.

Hopkins, M., Spillane, J. P., Jakopovic, P., & Heaton, R. M. (2013). Infrastructure redesign and instructional reform in mathematics: Formal structure and teacher leadership. The elementary school journal, 114(2), 200-224.

Law, N., Niederhauser, D. S., Christensen, R., & Shear, L. (2016). A multilevel system of quality technology-enhanced learning and teaching indicators. Journal of Educational Technology & Society, 19(3), 72.

Law, N., Yuen, J., & Lee, Y. (2015). Precarious School Level Scalability Amid Network Level Resilience: Insights from a multilevel multiscale model of scalability. Paper presented at the American Education Research Association Conference 2015, Chicago.

Looi, C. K., & Teh, L. W. (Eds.). (2015). Scaling Educational Innovations. Singapore: Springer

Penuel, W. R. (2019). Infrastructuring as a Practice of Design-Based Research for Supporting and Studying Equitable Implementation and Sustainability of Innovations. Journal of the Learning Sciences, 1-19.

Penuel, W. R., Fishman, B. J., Haugan Cheng, B., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. Educational researcher, 40(7), 331-337.

Spillane, J. P., Hopkins, M., & Sweet, T. M. (2017). School District Educational Infrastructure and Change at Scale: Teacher Peer Interactions and Their Beliefs About Mathematics Instruction. American Educational Research Journal, 55(3), 532-571. doi:10.3102/0002831217743928

Stein, M. K., & Coburn, C. E. (2008). Architectures for Learning: A Comparative Analysis of Two Urban School Districts. American Journal of Education, 114(4): 583-626.

Voogt, J., Laferrière, T., Breuleux, A., Itow, R. C., Hickey, D. T., & McKenney, S. (2015). Collaborative design as a form of professional development. Instructional science, 43(2), 259-282.

Wenger, E. (1998). Communities of practice, learning, meaning and identity. Cambridge University Press.

Yin, R. K. (2008). Case study research: Design and methods (4th ed.). Thousand Oaks, CA: Sage Publications.

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