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Retooling Chinese Primary School Teachers to Use Technology Creatively to Promote Innovation and Problem Solving Skills in Science Classrooms

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This paper reports on the initial phase of a Professional Learning Program (PLP) undertaken by 100 primary school teachers in China that aimed to facilitate the development of adaptive expertise in using technology to facilitate innovative science teaching and learning such as that envisaged by the Chinese Ministry of Education's (2010-2020) education reforms. Key principles derived from literature about professional learning and scaffolding of learning informed the design of the PLP. The analysis of data revealed that the participants had made substantial progress towards the development of adaptive expertise. This was manifested not only by advances in the participants' repertoires of Subject Matter Knowledge and Pedagogical Content Knowledge but also in changes to their levels of confidence and identities as teachers. By the end of the initial phase of the PLP, the participants had coalesced into a professional learning community that readily engaged in the sharing, peer review, reuse and adaption, and collaborative design of innovative science learning and assessment activities. The findings from the study indicate that those engaged in the development of PLPs for teachers in China need to take cognizance of certain cultural factors and traditions idiosyncratic to the Chinese educational system. A set of revised principles is then presented to inform the future design and implementation of PLPs for teachers in China.

Introduction

In recent years, one major priority of the Chinese Ministry of Education has been for their schools to become more "student-oriented" in nature and to develop in their students a sense of innovative spirit, creativity and good problem-solving skills (Los Angeles Times Editorial, 2012; Peoples' Republic of China, 2010). A major impetus for these reforms has been economic in nature and is based on the belief that China's future economic wellbeing is dependent on the ability of the country's populace to innovate, be creative and to analyze and solve problems (Dello-Iacovo, 2009; Hu, 2010).

Unfortunately within China, the vision implicit in these reforms generally is not being achieved in practice (Guan & Meng, 2007; Zhong, 2006). In most cases, teachers are simply continuing to teach as before; their methods continue to be based more on textbook and preparation for examinations than the revised curriculum standards (Shan, 2002). Thus within China, there is awareness about the need for improved professional learning programs to support the reform process (Ryan, Kang, Mitchell, & Erickson, 2009).

This paper reports on a professional learning program in China. The overall aim of the four-day program was to facilitate the development in the participants of adaptive expertise to use technology innovatively to facilitate the implementation of socio-constructivist science teaching/learning practices in their schools. Adaptive expertise is the ability to meaningfully apply learned knowledge flexibly and creatively (Baroody & Dowker, 2003, p. xi)

Although the study occurred in China, many of the issues with respect to professional learning by teachers identified during the course of the study are not unique to China. Many other countries (e.g., other Asia-Pacific rim nations such as Singapore, Korea, Vietnam, Malaysia, and Japan) are currently engaged in reforms similar to those in China (Los Angeles Times, 2012; Tan & Gopinathan, 2000) in order to cope with the effects of globalization. A review of the literature indicates that these countries are experiencing problems similar to those being experienced in China (see Coll & Taylor, 2008). Thus, many of the key issues identified and discussed in this paper have implications for professional learning programs in other countries engaged in the process of introducing into their schools "student-oriented" reforms in science and technology education.

Professional Learning Program

The participants in the professional learning program were 100 primary school teachers from 32 administrative divisions in China. The program consisted of a sequence of lectures, presentations and open forums presented in plenary group sessions, workshop and reflection sessions conducted in four workshop groups of 25 teachers split into teams of 3-4, and on-line Moodle® discourse sessions. The program focussed on: (1) Inquiry and project-based learning of science with LEGO® Education Toolsets, (2) Establishment of knowledge-building professional learning community, and (3) How inquiry and project-based learning can be implemented in Chinese primary school science. During the course of the program, the participants explored how design and problem solving activities based around LEGO® Education Toolsets can be utilized to facilitate innovative science teaching and learning. These activities were utilized for three reasons. First, these activities can provide a nexus between theory and practice (Chandra & Chalmers, 2008). Second, well-designed LEGO® robotic activities can provide contexts where existing theoretical frameworks for problem solving in science can be applied with ease and efficiency (Rogers & Portsmore, 2004). Third, LEGO® Education Toolsets had recently been supplied to the participants' schools by the LEGO® Foundation, Semia Ltd., and the Ministry of Education-People's Republic of China.

The design of the four-day long professional learning program was informed by the principles for effective professional learning programs in mathematics and science education presented in Table 1. These principles were derived from a review of the literature about professional learning and the scaffolding of learning.

Table 1
Principles for Effective Professional Learning Programs

Principle	Provenance of principle
1. Have a clear image of effective classroom learning and teaching	Loucks-Horsley Love, Stiles, Mundry, & Hewson (2003); National Academy of Sciences (1996)
2. Integrate with the educational system	Loucks-Horsley et al. (2003)
3. Develop teachers' conceptual knowledge, practical skills, and pedagogical content knowledge to broaden their teaching approaches	Dede (2006); Loucks-Horsley et al. (2003); Kubitskey & Fishman (2007); National Academy of Sciences (1996)
4. Prepare and support teachers to serve in leadership roles	Loucks-Horsley et al. (2003); National Academy of Sciences (1996)
5. Build a learning community of teachers	Kubitskey & Fishman (2007); Smith & Gillespie (2007); Tytler, Symington, Darby, Malcolm, & Kirkwood (2011)
6. Use instructional methods that mirror the methods to be used with students a. Professional learning programs should provide participants with conceptual frameworks that enable them to understand their own and their students' thinking and thus be able to recognize which elements of the reforms are critical, which must be adapted, and which must be reinvented. b. Professional learning program activities should scaffold the social construction of "big ideas" by the participants c. Professional learning program activities should be problem-based d. Attention should be paid to prior teacher knowledge and beliefs about the nature of science and the nature of teaching and learning e. Science content should be related to technological and societal issues thereby connecting science to the real world and how we live in it f. Theory should make a strong connection to teachers' work context and experiences and use learning activities that make abstract concepts personal g. A strong emphasis on analysis and reflection, and integration and planning that enables teachers to anticipate and plan for institutional barriers to reforms rather than just on demonstrating techniques	Loucks-Horsley et al. (2003); Smith & Gillespie (2007) Kubitskey & Fishman (2007); Pea (2004) Smith & Gillespie (2007) Dede (2006); Loucks-Horsley et al. (2003) Putnam & Borko (2000) Kubitskey & Fishman (2007); Smith & Gillespie (2007) Dede (2006); Kubitskey & Fishman (2007)
7. Teachers should have opportunities to try out developing concepts by making applications in their classrooms	Kubitskey & Fishman (2007); Smith & Gillespie (2007)

Principle 1 is reflected in the constructionism framework that informed the professional learning programs design. Constructionism is a theory of learning and a strategy for education (Kafai, 2006; Papert, 1991). According to Papert (1991, p.1), "Constructionism… shares constructivism's view of learning as "building knowledge structures" through progressive internalization of actions… It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe." In addition to being philosophically consistent with the goals of the Ministry of Education's reforms (People's Republic of China, 2010), this framework also helped to integrate the professional learning program into the educational system in which the participants were being asked to implement the reforms (Principle 2).

Principles 3, 4 and 5 are reflected in the overall aim of the professional learning program about the development of adaptive expertise which encompasses a range of cognitive, motivational, and identity components, as well as dispositions (Crawford, Schlager, Toyama, Riel, & Vahey, 2005). Thus, the professional learning program primarily focused on facilitating the development of science pedagogical content knowledge (PCK), teacher confidence, and teacher identity necessary for adaptive expertise in teaching science with technology.

Principle 6a was operationalized by the introduction of a socio-constructivist conceptual model in the schedule of activities. The model was introduced to facilitate deeper reflection and constructive dialogue to mediate the construction of not only physical artifacts (the LEGO® constructions) but also of conceptual artifacts such as frameworks and strategies for facilitating knowledge-building (Scardamalia, 2002), innovation, and creativity in science classrooms. Knowledge-building involves having learners make a collective inquiry into a specific topic, and come to a deeper understanding through interactive questioning, dialogue, and continuing improvement of ideas (Scardamalia, 2002). The conceptual model (presented in Figure 1) has two components: (1) a pedagogical model and (2) a set of learning outcomes.

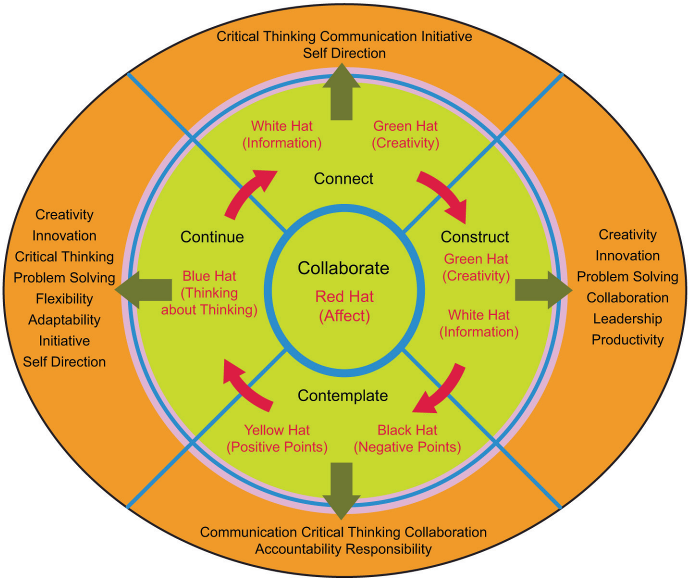

Figure 1. Socio-constructivist conceptual model.

The pedagogical model was the outcome of the integration of de Bono's (1999) Six Hats process for thinking and problem solving with LEGO® 4Cs process for constructionism-based learning (http://www.legoeducation.com.hk/index.php/en/about-us/16). However, due to perceived limitations of these two frameworks in the context of the current professional learning program, a fifth C was added to the 4Cs process: Collaboration. Within our model, collaboration adopted a knowledge-building quality (Scardamalia, 2002); the participants were expected to take epistemic agency and be active contributors towards community advancement of knowledge about the teaching/learning of science. Knowledge-building collaboration is encompassed throughout the four thinking and problem solving phases: Connect, Construct, Contemplate and Continue (Figure 1). In our model, we also have extended the definition of Red Hat beyond "instinctive gut reactions" (de Bono, 1999) to include reasoned affective emotions. This enabled the placement of Red Hat at the core of our pedagogical model with collaboration so that both affective and cognitive domains could be addressed during all four thinking and problem solving phases.

The learning outcomes were derived from Schrum and Levin's (2009) list of 21st Century "learning and innovation skills" and "life and career skills". These learning outcomes were related to the four thinking and problem solving phases of the pedagogical model.

Many learners in socio-constructivist learning environments tend to be overwhelmed not only by the amount of information they are being asked to process but also by being required to step, cognitively speaking, into the realm of uncertainty (Alsup, 2004). Classroom observation indicates that this was the prior experience with professional learning programs of many participants in our study. To address this issue, teacher learning was scaffolded (Principle 6b) by "channelling" and "focusing" (Pea, 2004).

The term "channelling" was derived from Pea's (2004) seminal paper on scaffolding in which he pointed out that learning could be scaffolded by placing constraints during the earlier stages on the openness and complexity of a sequence of learning activities. Channelling was achieved by focussing on how three specific strands within the revised science curriculum (*Living things and their habitats*, *Forces and movement*, and *Magic forces*) could be innovatively implemented through technology. Channelling was further achieved by the gradation of the "design challenges"; as the teachers progressed through the design challenges, channelling was reduced and the tasks became more complex and open-ended in nature (Table 2).

Focussing was achieved by intentionally highlighting key relevant features during workshops and reflection sessions. During the workshops, this was done by the utilisation of activity sheets and lesson plan templates that focused the teachers' attention on exploring key "big ideas" subsumed within the activities. For example, the relationship between each of the "design activities" and science "big ideas" subsumed within the "Living Things", "Forces and Movement" and "Magic Forces" strands of the Chinese science curriculum was explored and made explicit. Focussing was further enhanced during the course of the reflection sessions where teachers revisited and consolidated the key "big ideas" they had explored during the course of the workshop.

Principles 6c-g were reflected in the tasks that the teachers engaged in during the course of the workshops and in the reflection sessions. Principles 6c and 6d were manifested in the nature of the "design challenges"; in addition to being problem-based (Principle 6c), they were designed to challenge the teachers' existing knowledge and beliefs about the nature of science, teaching and learning (Principle 6d). For example, in order to confront the teachers' existing dispositions to "silo" science, during the *Contemplate* and *Continue* phases of the "design challenges", each team was required to focus on cross-discipline science, mathematics, technology, engineering and language possibilities subsumed within each task; a similar cross-disciplinary focus was employed during the course of the "Planning a Science Unit" task.

Table 2

Channeling

Task	Design Challenge	Curriculum Strands	Timetable	Degree of Channeling	Degree of Complexity	Degree of Openness
The Zoo	Build robot models of zoo animals from on-line designs with LEGO® We-Do Kit Link the robotic animals to their habitats	Living things and their habitats	Day 1-Session 4	High	Moderately Low	Low
Freewheeler	Build a Freewheeler car from instructions in book Use the Freewheeler to test which will roll further: Heavier or lighter cars? Or Cars with bigger or smaller wheels?	Structure and Design Process and Design Control and design	Day 1-Session 6	Moderately High	Moderately Low	Moderately Low
Building a Drawbridge	Design and build a drawbridge with LEGO® We-Do Kit Create a simple robotic program to operate the Drawbridge Identify forces that make a drawbridge work	Magic Forces	Day 2-Session3	Moderate	Moderately High	Moderately High
The Machine	Build simple machines including levers, gears and pulleys using GT2201 kit. Design and analyze the optimal structure and process of a complex machine Identify and understand the different structures of simple machines	Structure and Design Process and design	Day 2-Session 4	Low	Moderately High	High
LEGO® Science Unit	Design a science unit that utilizes LEGO® Education Toolsets	Open	Day 3-Sessions 2 and 3	Very Low	High as Desired	High

The "design challenges" addressed Principle 6e by providing contexts that related the learning of science concepts (e.g., forces) to the real world and how we live in it (e.g., drawbridges and simple machines such as tipping trolleys). Principles 6f-g were operationalized when the teams of teachers were asked to reflect on the "design challenge" tasks and then engage in the design of a science unit that could be implemented in their schools.

Principle 7 was operationalized in the implementation phase of the program. During this phase, the teachers were required over a period of one school year to apply the knowledge, skills and strategies they had developed during the workshops and reflection sessions in classrooms at their schools. They also were required to disseminate this information to teachers at other schools in their regions (thus also further operationalizing Principles 4 and 5).

Evaluation of Program

The evaluation of the program was guided by the following two research questions:

(1) What advances had been made by the teachers towards the development of adaptive expertise about teaching science with technology?

(2) What factors had influenced those advances?

Because traditional quasi-experimental evaluation methodologies would be unable to adequately identify incremental advances towards adaptive expertise made by the teachers, nor be able to provide insights into what factors influenced those advances, an interpretative methodology was utilized in this evaluation study.

Collection and Analysis of Data

In order to achieve "data triangulation" (Yin, 2009), qualitative data from all participants were collected from sources listed in Table 3. It was envisaged that each data source would contribute towards the development of a richer understanding of the whole phenomenon.

Table 3
Collection of Data

Source of data	When	Focus
Pre-Survey	Beginning of Day 1	Backgrounds and prior experiences of teachers with professional development programs and the implementation of new curriculum initiatives in their schools
Observation notes of facilitators	All sessions	Factors influencing changes in PCK
Video-taped observations	All workshop and reflection sessions	Changes in PCK Factors influencing changes in PCK
On-line individual reflections	End of each day	Changes in PCK Factors influencing changes in PCK
Team reflections (online via Moodle®)	Reflection sessions	Changes in PCK Factors influencing changes in SMK and PCK
Science Unit Plan	End of Day 3	Changes in PCK
Focus group interviews	End of Day 3	Changes in PCK Factors influencing changes in PCK

In order to ascertain advances made towards the development of adaptive expertise, data from all seven sources went through three stages of analysis. First, data were analyzed in order to ascertain changes to the teachers' repertoires of pedagogical content knowledge (PCK) about the teaching of science. This analysis was informed by an adaption of Ball, Thames and Phelps' (2008) work on PCK. Ball, Thames and Phelps (2008) identified three domains of PCK: Knowledge of content and students - knowledge that combines knowing about students and knowing about science, Knowledge of content and teaching - knowledge of the design of science instruction that combines knowing about teaching and knowing about science, and Knowledge of content and curriculum - knowledge that combines knowing about curriculum and knowing about science. Second, the data were analysed in order to ascertain changes in the teachers' levels of confidence to implement the socio-constructivist teaching/learning strategies. Prior research (e.g., Bencze & Hodson, 1999; Leung, 2008) clearly indicates that extension of professional confidence plays a significant role in the adoption by teachers of socio-constructivist curricula reforms. Third, the data were analysed in order to ascertain changes in teacher identity. The successful implementation of socio-constructivist teaching/learning strategies requires significant shifts in teacher identity (i.e., their view of their professional role) towards that of a constructor of knowledge engaged in the design and implementation of science learning activities that involve both student-centred and teacher-directed learning (Taber, 2011).

In order to ascertain factors that influenced these changes, data from observation notes and videos, individual and team reflections, and focus group interviews were analyzed in order to ascertain the impact of the: (1) conceptual model, (2) scaffolding, (3) learning activities, and (4) learning environments.

The data went through three major phases of analysis: reduction, display, and conclusion drawing and verification (c.f., Miles and Huberman, 1994). Authors 1-4 performed the initial analysis. In order to achieve investigator triangulation (Yin, 2009), the conclusions drawn from this analysis were evaluated by having the fifth author go through the data looking for negative evidence. As Sowden and Keeves (1990) point out, while the failure to find negative evidence after a deliberate search does not and cannot establish the "truth" of a conclusion, it however does increase the likelihood that the original conclusions are sound.

Results

The results are presented in two sections that correspond to the two research questions that guided the evaluation of the professional learning program:

1. Advances made by the teachers towards the development of adaptive expertise, and
2. Influencing factors.

Advances Made by the Teachers Towards the Development of Adaptive Expertise

The analysis of data revealed that the participants had made substantial progress towards the development of adaptive expertise in using technology innovatively to facilitate science teaching and learning. This was manifested in three ways: 1) advances in the participants' repertoires of pedagogical content knowledge, 2) changes to their levels of confidence, and 3) changes in their identities as teachers.

Knowledge of content and students

The analysis of data revealed that the participants had advanced their repertoires of knowledge of content and students along two dimensions identified by Ball, Thames and Phelps (2008): *conceptions of the student* and *knowledge about students learning science*.

Conceptions of the student: One of the major tenets of constructionism that contrasts it with traditional teacher-centred didactic models of education is its conception of the student as an active learner (Papert, 1991). Insights garnered from the analysis of classroom observation and focus group data revealed that most participants had entered the professional learning community with conceptions of students as passive learners whose role was to internalize and accurately reproduce science knowledge transmitted to them by their teachers and/or textbooks. The analysis of data from Days 2-4 indicates that most participants were well on the way to developing conceptions of students as active learners considerably responsible for their own learning, conceptions consistent with the socio-constructivist goals of the science curriculum reforms. This change in conception was reflected in their developing realisation of the importance of learners constructing their own understanding of science from hands-on activities rather than being told. As one participant noted in her final reflection:

> I can see that all of us now realize that we have to work closely with our students to encourage them to explore on their own and with team members. We should not pay so much attention to getting our students only to rote learn, to complete the curriculum and to pass the examination. We need to push our students to be active learners, just like what we have been doing here ourselves.

Concurrent with the emergence of conceptions of students as active learners were three other changes in knowledge of content and students conceptually consistent with one of the major goals of the science education reforms, namely to encourage more inquiry learning and problem solving in order to change students from receptive to active learners (People's Republic of China, 2010). First was the emergence of the notion that one of the best ways to facilitate active learning was to ensure students learnt how to work collaboratively in problem solving teams. Second was the emergence of the notion of multiple solutions and multiple solution paths. Third was the emergence of the notion that making mistakes and learning from them was an essential dynamic to becoming an active learner. As one of the more experienced participants commented,

> If I hadn't attended this professional learning my method would have been to get the students to construct the model and they would have constructed 50 of the same looking models. However, with my newly acquired experience from attending this program, I will continually be asking my students many questions to encourage them to think more deeply and to come up with more solutions. I would also inform my class that there is more than one solution. If I give my students the right amount of support (which I now know how to do) then they will become very creative and think up all sorts of innovative solutions to the science problems that I present to them in class!

Knowledge about students learning science: Most participants were able to successfully integrate the content knowledge they had developed during the program with their prior experiences to generate significant advances in knowledge of content and students about:

(1) what their students were likely to think, (2) what their students would find confusing, (3) what their students were likely to do, and (4) whether their students will find it easy or hard when engaged in science problem solving design tasks. These advances enabled the participants to incorporate into their science lesson plans design challenges they could justify as being appropriate for their students and many interactive teaching/learning strategies not frequently utilized in Chinese classrooms (e.g., open-ended focus questions, discussions about how/what had been learnt, and reflection on how the process and product could be improved).

The analysis of the assessment within each team's science lesson plans also revealed that the participants had made considerable advances in terms of addressing one of the major goals of the science education reforms, namely to develop new approaches and techniques for assessment (People's Republic of China, 2010). They had come to understand how planning to hear and interpret students' emerging and incomplete thinking was a crucial component of socio-constructivist teaching. This was well exemplified by the questions included in the teams' lesson plans. For example, in Team 3-2's *Mountain Stretcher* lesson plan, teachers would challenge their students to design a mountain rescue stretcher (that is sturdy, easy to work, and safe and comfortable). Team 3-2 came from a mountainous region of China where mountain rescues are a common occurrence. Prior to constructing their stretcher, the teachers' lesson plan indicated that they would ask their students this question to ascertain their understanding of the task at hand: *If you make a mountain rescue stretcher with LEGO® 9686 kits, how would you make it? Please draw your ideas.* Then in order to ascertain if students have "got" the scientific ideas after completing their stretcher, the following questions would be asked: *Explain with science concepts why your stretcher is the way it is?* And; *Did the stretcher work as you expected? Which parts did and which parts did not?*

Knowledge of content and teaching

Two important dimensions of knowledge and content of teaching identified by Ball, Thames and Phelps (2008) are: *design of learning activities and design of assessment activities.* The analysis of data revealed that the participants had advanced their repertoires of knowledge about the design of science instruction along these two dimensions.

Design of learning activities: The analysis of the science lesson plans indicated that by the conclusion of the program, the participants were able to use, adapt and in some cases envision models of instructional design that were flexible, adaptive and based on innovative instructional methods as well as the creative use of LEGO® Education Toolsets and other materials.

This finding was confirmed during the analysis of data from their reflections and focus interviews; in both these contexts, the participants consistently indicated that they had learned to recognize what kinds of learning experiences facilitated their students' learning. This is reflected in the following comment from a participant from Shandong province:

> Initially when we were given a task to do we felt that it was so easy! But then when we tried it out with our first model, we discovered that it didn't quite work and there were many problems with the model that we had designed. After much discussion among team members we re-designed the model

> and came up with other solutions. We were a bit apprehensive because our view was that the teachers (i.e., university facilitators) did not provide us with much information, and we were not accustomed to the way they were teaching us. How are we to perform the task with so little instruction? But once we became comfortable with the new teaching approaches, we enjoyed the lessons because they were forcing us to be active learners, to use the 4Cs and to actually think a lot deeper. We finally were learning by doing just as we should be doing with our own students in our classes when we return to our own school.

Design of assessment activities: The analysis of data also indicated that the program had succeeded in changing teachers' awareness of what was worth assessing and how/when it could be assessed. Thus, they were well on the way to acquiring the knowledge necessary for effectively implementing the goal of developing new approaches and techniques for assessment included in the science education reforms. For example, all teams' lesson plans included assessment to evaluate the entire design and challenge process and not the outcomes alone. This is well exemplified by Team 2-5's evaluation rubric for their *Lever* lesson plan. This evaluation rubric focused not only on Product (*Lever functions* and *Connection to life*) and Process (*Active thinking* and *Running into difficulties*) but also on Scardamalia's (2002) knowledge-building notions of epistemic agency and collective responsibility (*Division of labour*).

All science lesson plans demonstrated that when implemented in classrooms, they would provide students with opportunities to critically self-assess and reflect upon their learning during the course of the science unit. This is well exemplified in Team 3-2's *Mountain Stretcher* lesson plan where the students are asked the following questions: (1) *What was this challenge about?* (2) *Where did your ideas come from?* (3) *How did you turn your ideas into a model?* (4) *Which methods were most effective?* (5) *What ideas did not work?* (6) *What did you learn from this challenge?*

Knowledge of content and curriculum

The analysis of the science lesson plans and data from the reflections and observations of the teams' presentation of the science lesson plans revealed that the participants had made considerable advances to their repertoires of curriculum planning knowledge. For example, all participants had developed criteria that could serve as indicators or counter-indicators for the implementation of particular LEGO® *Education Toolsets*-based science learning activities in their classrooms.

Most participants also had made considerable advances to their repertoires of *lateral curriculum knowledge*, knowledge of the curriculum being taught in other classes (Ball, Thames, & Phelps, 2008). In their lesson plans, many teams intentionally drew on their knowledge of what was being taught in other subject areas and integrated this into their science learning activities. This is well exemplified by Team 4-4's integration of science with language arts in their *Insect Village* lesson plan. As this team indicated in their Task Description,

> Our activity is based on a text "Insects' Village" in the Chinese textbook. After the Chinese lesson, we'll use video clips to arouse students' interest and ask them to construct an Insects' Village. Each team will construct an insect model and construction of the model will based on an insect's pictures.

Changes in participants' level of confidence

Initially, most participants lacked confidence about their ability to implement learning activities based around design challenges in their classrooms. However, after their participation in the program activities (during which they advanced their repertoires of PCK), the participants felt more confident in their abilities to implement the design challenges. As one of the participants commented at the end of Day 3,

> I feel that after this experience my own level of skills has greatly increased. I now feel confident enough to use LEGO® -based science learning activities in my classroom to enhance student learning…

It was interesting to note that like many other participants, this teacher felt confident that he would not only be able to incorporate the design challenges in science but also across other discipline areas too.

Change in identities as teachers:

The pre-survey revealed that most participants initially felt caught in a dilemma in which they had to choose between two alternatives: meeting the expectations of administrators, peers, parents and students that they "cover" the curriculum content *or* implementing the socio-constructivist goals of the new curriculum. However, by the end of the program most participants had progressed beyond being (just) curriculum implementers to purposeful learning designers. Thus, rather than perceiving that they were in an awkward position of having to make a difficult choice between either coverage of content or implementation of the socio-constructivist goals of the new curriculum, most participants realized that through innovative and creative learning unit design and teaching strategies, *both* the content and the socio-constructivist goals of the new science curriculum could be addressed. Concurrent with their emerging identities as purposeful learning designers were changes to their notions about their roles as teachers. Rather than being transmitters of knowledge, they now perceived themselves as co-constructors, mediators, and inductors of their students into a scientific community of practice.

Influencing Factors

Two major reasons for the considerable progress towards the development of adaptive expertise were identified:

(1) Emergence of a knowledge-building professional learning community; and

(2) Participants "buying in" to the Program.

Emergence of a knowledge-building professional learning community

By the final two days of the program, the participants had coalesced into a professional learning community that readily engaged in the sharing, peer review, reuse and adaption, and collaborative design of science learning and assessment activities. As one of the participants noted:

> When we started on the first day we were not confident to speak up publicly and did not feel that we were learning very much. However, by the third day all teachers in each team or group were actively engaged in all activities, presentations and discussions.

Indeed the cohort of participants exhibited many of the qualities identified by Scardamalia (2002) as being characteristic of successful knowledge-building communities. For example, they engaged in knowledge-building discourse during which they not only shared knowledge but also refined, transformed and advanced PCK about the teaching/learning of science with technology. Much of this refinement, transformation and advancement of knowledge was stimulated by the participants setting forward their ideas and negotiating a fit between their ideas and the ideas of others to spark and sustain the advancement of PCK.

The emergence of a knowledge-building professional learning community was mediated by the following four factors: (1) Conceptual model, (2) Scaffolding, (3) Diversity of experiences and ideas, and (4) Provision of spaces for private and public discourse.

Conceptual model: In addition mediating the construction of *LEGO*® artifacts, the conceptual model provided the participants with a shared meta-language that facilitated within- and between-team knowledge-building discourse. All teams utilized the 5Cs component of the model when engaged in discourse about the planning, sharing, refinement, transformation, and advancement of their own and other teams' learning and assessment activities. Thus, there was effective negotiation of ideas during within- and between-team discourse about how to best link key scientific concepts to their students' prior knowledge and experiences during the Connect phase of learning activities. There also was most effective negotiation of ideas during discourse about how to advance the quality of the Contemplate and Continue phases within the learning activity plans.

Scaffolding during Phase 1: During Days 1-2, an extensive amount of time was spent on presenting, modelling and practicing strategies for establishing knowledge-building discourse, and on discussions and reflective activities. By the beginning of Day 3, all participants had acquired the comfort, skill and confidence to articulate their views, challenge those of others and to come to better understandings as a community.

Diversity of experience and ideas: According to Scardamalia (2002), idea diversity is essential to the development of knowledge advancement, just as biodiversity is essential to the success of an ecosystem. In this study, it was found that the great diversity of experiences and ideas brought to the program by the participants facilitated the creation of a rich environment for ideas to evolve into new and more refined forms.

Spaces for private and public discourse: Brett and Hewitt (2010) pointed out that one problem with workshops/seminars is that participants may be reluctant to publicly share nascent ideas, for fear that they will be ridiculed or criticized, or that their peers or facilitators will think less of them. Within China, this is compounded by *shi mianzi* - loss of face or respect. Being the first to provide own "wrong" or "inconsiderate" ideas publicly may cause self-embarrassment and be seen as not smart. Thus, in this study, we provided the participants with Team workshop area space and private on-line Moodle® spaces for team and individual reflection where they could "safely" gestate nascent ideas prior to publicly sharing them. Comments made during the focus group interviews indicated that many of the participants felt that these private spaces had done much to facilitate their construction of knowledge.

Participants "buying in" to the Program

When the participants were introduced to design challenges on Day 1, many expressed sentiments similar to this:

> We do not have time to concentrate on the "process" which incorporates the notion of students being actively engaged and working as a team… We never have time to allow students to reflect…[Team 3-6 member]

By the end of Day 3, most participants had overcome their initial scepticism and had been convinced that the information being presented could improve their teaching. Thus, they had been motivated to learn new practices, change existing practices, or adopt practices they had previously chosen not to use. That is, the participants had "bought-in" to the program. According to Kubitskey and Fishman (2007), the success of a professional learning is highly dependent on participant "buy-in".

Data from the reflections and the focus group interviews indicated that participant "buy-in" had been mediated not only by the emergence of a knowledge-building professional learning community but also by two other factors: (1) learning activities, and (2) ambience of the learning environment.

Learning activities: The "design challenges" based around the LEGO® Education Toolsets provided the participants with contexts for first looking at their own learning which in turn provided them with a lens to relook at learning from a student's perspective. Then, as one of the teachers said during a focus group interview on Day 4:

> We realized that for us to be good teachers we need to be able to see the classroom activities from the students' perspective. First we need to learn ourselves just like being a student and then and only then can we be better teachers who teach these students to be active learners.

Engagement in the "design challenges" thus facilitated participant "buy-in" by addressing what Day (1999) suggested usually motivates teachers to change; identifying how to recognize what kinds of experiences actually can make a difference to the lives of the students they teach.

Ambience of learning environment:

The learning activities helped to establish and maintain an ambient learning environment. The level of difficulty of each of the design challenges was intentionally set to be challenging but not too difficult. Initially, the design challenges were rather simple and closed in nature but gradually became more open-ended and complex in nature (see Table 2). Also, consistent with the constructionism framework underlying the program, the notion of being "wrong" (i.e., failing) when constructing the *LEGO*® artifacts was replaced with the notion of having bugs in the design which one could de-bug.

The establishment and maintenance of an ambient learning environment also was mediated by the modelling of knowledge-building discourse and the ample time left for discussion provided by the facilitators. In addition to providing the participants with model lesson plans and activity templates, the facilitators "gently" modelled knowledge-building discourse strategies when asking questions and providing feedback to participants. As one of the participants said on the final day:

> The facilitators worked with us like they were our friends – gently guiding us along the way and putting us in the right direction. They helped us to think and kept pushing us to be creative.

Ambience was further enhanced by the facilitators overtly recognising the local knowledge and expertise of the participants and overtly adopting the roles of collaborators, co-learners and co-constructors of new science education programs for Chinese schools rather than exporters of new education programs to China.

DISCUSSION

By the end of four-day program, it was noted that a knowledge-building professional learning community was emerging. The emergence of this knowledge-building community mediated substantial progress towards the development of adaptive expertise. This was manifested by advances in the participants' repertoires of pedagogical content knowledge (PCK), levels of confidence and identities as purposeful learning designers/implementers. Reciprocal mediation relationships (Flavell 1982) were found to exist between these derived outcomes (Figure 2). Flavell (1982) defined reciprocal mediation: Item X continually facilitating the development of Item Y and vice versa. Each small step in knowledge of content and students, knowledge of content and teaching, or knowledge of content and curriculum often mediated small developmental steps not only in the other categories of PCK but also in confidence and identities and vice versa.

Our analysis of the data also indicated that the development of the derived outcomes was predicated by two mediating outcomes: the emergence of a knowledge-building professional learning community and participant buy-in. We found a reciprocal mediation relationship existed between the two mediating outcomes (Figure 2). The emergence and further development of the two mediating outcomes was in turn mediated by the six instrumental components of the seminars/workshops.

These findings in general endorse the principles (Table 2) utilized to inform the design and implementation of the professional learning program. However, the findings also indicate that this list of universal principles requires amendment to take cognizance of the cultural factors and traditions idiosyncratic to the Chinese educational system. We feel that Principles 5 and 6 need revision and Principles 8 and 9 need to be added (Table 4).

Because the traditional top-down culture inherent within the Chinese educational system is not amenable to innovation, diversity of ideas, and collaboration between teachers, most Chinese teachers feel threatened and in some cases overwhelmed when asked to engage in professional learning programs with socio-constructivist goals and methodologies. The findings indicate that addressing this issue should be the priority during the initial phase of a professional learning program and not something to be addressed later on. This viewpoint is reflected in the revised version of Principle 5.

To enact revised Principle 5 in Chinese contexts, professional learning program developers need to meticulously plan for the scaffolding of knowledge-building activity. In this study, it was found that having the participants initially engage in the collaborative construction of LEGO® physical artifacts was a major factor contributing towards the success of the program. This seemed to act as an ice-breaker that overcame the participants' initial reticence to engage in collaborative knowledge-building activity. This finding is reflected in revised Overall Principle 6. We also found that providing a conceptual framework that provided both structure and meta-language and by utilising channelling and focusing strategies also did much to scaffold knowledge-building activity. These two findings are reflected in revised Principles 6a-b. Revised Principle 6c is based on our finding that encouraging the participants to generate a diversity of physical and conceptual artifacts was a major factor towards establishing and maintaining knowledge-building activity.

Principle 8 takes cognizance of Chinese teachers' fear of *shi mianzi*. Within Chinese culture, it is critical that you avoid losing face or causing the loss of face at all times. In our study, we found that this issue was addressed by the provision of private individual and team spaces. Principle 9 is based on our finding that having non-science specialists in our professional learning program workshop groups facilitated the creation of rich environments for ideas about the teaching/learning of science with technology to evolve and then be transformed into new and more refined forms.

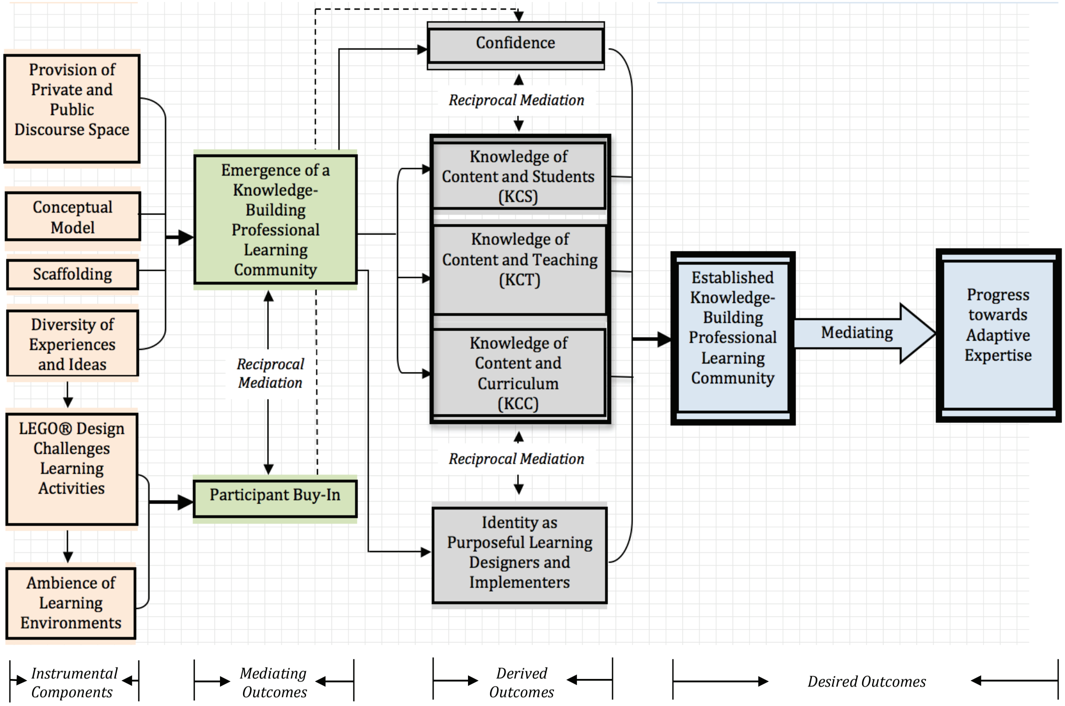

Figure 2. Reciprocal mediation relationships between outcomes.

Table 4

Amended Principles for Effective Professional Learning Programs in China

Revised Principles
Principle 5: The initial focus of the PLP should be the establishment and maintenance of a knowledge-building professional learning community. *Overall Principle 6: PLP workshop/seminar activities should focus on facilitating the social construction of both physical and conceptual artifacts about the teaching/learning of science that are amenable to knowledge-building discourse and improvement.* *Principle 6a: PLPs should provide participants with conceptual frameworks that provide both the structure and meta-language to facilitate the social construction of physical and conceptual artifacts about the teaching/learning of science.* *Principle 6b: PLP activities should scaffold the social construction of physical and conceptual artifacts about the teaching/learning of science via the means of channeling and focusing.* *Principle 6c: PLP workshop/seminar activities should facilitate the social construction of a diversity of physical and conceptual artifacts about the teaching/learning of science that are amenable to knowledge-building discourse and improvement.*
Additional Principles
Principle 8: Provision should be made for private individual and team spaces within PLPs for the gestation of nascent ideas. *Principle 9: The cohort of teachers at science education PLPs should include not only science specialists but also specialists from across the whole curriculum to ensure a diversity of experience and ideas.*

CONCLUSION

To a great extent, the success of curriculum reforms such as those currently being implemented in China relies on the teachers' capability in implementation (Liu & Li, 2010). This issue was addressed in the overall aim of the professional learning program reported on in this paper: the development in the teachers of adaptive expertise to use technology innovatively to facilitate the implementation of socio-constructivist science teaching/learning practices in their schools.

By the end of the four-day program, the participants had made substantial progress towards the development of adaptive expertise in using technology innovatively to facilitate science teaching and learning. This was reflected in their increased levels of pedagogical content knowledge and confidence in their abilities to be purposeful learning designers engaged in the process of implementing both the content and the socio-constructivist goals subsumed within the science education reforms. Since their participation in the program, the participants have proceeded on to the implementation phase of the program. During this phase, the participants' contact with other members of the knowledge-building professional learning community was limited to on-line interactions. Whether or not the participants' adaptive expertise continued to develop during the one-year implementation phase of the program will be investigated in a follow-up evaluation study.

Although this study occurred in China, many of the issues with respect to teacher professional learning identified during the course of the study are not unique to China. A review of the literature indicates that many other Asia-Pacific and developing countries are experiencing problems similar to those being experienced in China (see Coll and Taylor 2008). For example, within these countries socio-constructivist reforms in science education often are being stymied by teachers' reticence to appropriate teaching/learning practices based on conceptions of teaching/learning at variance with their currently-held conceptions (Shan, 2002; Suzuki 2008). These currently-held conceptions emphasize a transmission model of teaching where the focus is on memorisation of textbook knowledge and preparation for examinations.

Thus the revised set of principles derived from the outcomes of this study could be applied to inform the design and implementation of professional learning programs in other Asia-Pacific countries currently engaged in the process of introducing "student-oriented" reforms in science and technology education. As in China, the successful implementation of new science and technology curricula standards in these countries requires changes in teachers' conceptions of school science and of effective teaching and in their ability to carry out student-centered classroom instruction and assessment.

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