Reforming the Preparation of Future STEM Teachers

Kar-Tin Lee[1], Rod Nason[2]
[1,2]Queensland University of Technology, Brisbane
k5.lee@qut.edu.au

Abstract: *This paper begins by identifying the key attributes for future STEM teachers. Then based on a review of the literature, a framework for informing reforms to pre-service teacher education programs to facilitate the development of these attributes in future STEM teachers is presented and discussed. This framework consists of a set of three principles together with eight strategies for the operationalization of these principles. During the discussion, the implications for the structure and implementation of future pre-service STEM teacher education programs are explored.*
Keywords: teacher education, adaptive expertise, pre-service teachers, teacher attributes

1. Introduction

In many countries throughout the world, "new" STEM education programs are being developed and/or implemented. The vision implicit in most of these programs is one where rigorous academic concepts are coupled with real-world lessons as all students (and not just those majoring in STEM) apply science, technology, engineering, and mathematics in contexts that make connections between school, community, and work (Tsupros, Kohler, & Hallinen, 2009). Thus, many of the "new" STEM programs place much emphasis on design and problem-solving in "intellectually messy" learning situations that weave together within and between the disciplines (Lesh &Doerr, 2003; Sanders, 2009). However, a review of the literature indicates this vision is far from being realized; more often than not what is happening is the grafting of "technology" and "engineering" layers onto standard science and mathematics curricula (Lantz, 2009).

Like many innovators in the field of STEM education, the authors of this paper contend if the vision implicit in most "new" STEM reforms is to be realized then a radical re-think of initial teacher education for STEM teachers is needed. To contribute to this process, in this paper we present a framework to inform the reformation of pre-service preparation of future STEM teachers.

2. Key Attributes of Future STEM Teachers

There is a growing consensus in the literature that many of the desired outcomes of the "new" STEM programs will not be achieved unless substantial changes also are made to pre-service teacher education programs (Cunningham, 2009; Custer & Daugherty, 2009; Hardy, Howes, Spendlove, & Wake, 2008). The major focus of these changes is an increased emphasis on the development of attributes in teacher education graduates of what can probably best defined as adaptive expertise (Bransford, Brown, & Cocking, 1999; Crawford, Schlager, Toyama, Riel, & Vahey, 2005).

Adaptive expertise is a construct derived from research on expertise, problem-solving and learning, that encompasses a range of cognitive, motivational, and identity or personality-related components, as well as habits of mind and dispositions (Crawford et al., 2005). According to Bransford et al. (1999), "Adaptive experts are able to approach a new situation flexibly and to learn throughout their lifetimes. They not only use what they have learned, they are metacognitive and continually question their current levels of expertise and attempt to move beyond them" (p. 48). Thus, teachers with adaptive expertise possess both the expert knowledge (Subject Matter Knowledge and Pedagogical Content Knowledge) that is necessary for high-quality performance and the ability to be flexible and inventive in the face of non-routine situations. They possess not only conceptual understandings, but also have access to procedural competencies, models of practice, and ways of monitoring their own development (University of Minnesota, n.d.).

STEM teachers with adaptive expertise also exhibit the disposition of reciprocity; they are more able to move beyond their identities as science, technology, engineering or mathematics teachers and be buoyed by a sense of discovery and enjoyment at interacting with others who come from a different perspective (Hardy et al., 2008). According to Hardy et al. (2008), they also display a willingness to go outside of their "silos" and engage in joint learning tasks with teachers from other STEM disciplines, express uncertainties and ask questions, take a variety of roles in joint learning enterprises and take others' purposes and perspectives into account. This set of teacher attributes probably is necessary condition for the successful implementation of the trans-disciplinary "intellectually messy" learning situations (Lantz, 2009) that form the basis of most "new" STEM curricula.

3. Facilitating the Development of Adaptive Expertise in Future STEM Teachers

Based on an extensive review of research and curriculum reform literature, we believe that the development of expertise in future STEM teachers can be facilitated by having pre-service teacher education programs focus on nurturing the development of:

1. Both within-discipline and trans-disciplinary STEM Knowledge;
2. Situated theoretical knowledge to underpin informed STEM educational practice; and
3. Positive attitudes and disposition towards STEM.

3.1. Nurturing Within-discipline and Trans-disciplinary STEM Knowledge

Lantz (2009) contends that "new" STEM is trans-disciplinary in nature; it offers a multi-faceted whole with greater complexities and new spheres of understanding that ensure the integration of disciplines. This integration of disciplines can be achieved through *context integration* and *content integration* (Moore, 2010-2015). Context Integration focuses on the content of one discipline and uses contexts from others to make the content more relevant. Content Integration focuses on the merging of the content fields into a single curriculum in order to highlight "big ideas" from multiple content areas (Moore, 2010-2015).

In order for teachers to be able to effectively plan learning activities involving context integration, it is necessary for them to have well-developed repertoires of subject matter knowledge (SMK) and pedagogical content knowledge (PCK) about the primary discipline in which the learning activities are situated (Custer & Daugherty, 2009; Sanders, 2009). For example, their repertoire of SMK should include advanced knowledge about how the discipline's "big ideas" relate to culture and society; this would facilitate the selection of appropriate contexts from other STEM disciplines. Therefore, it is crucial that pre-service teacher education should focus on the richness and depth of content knowledge, foundations, pedagogies, curriculum, research, and contemporary issues of one or preferably more of the STEM disciplines.

The effective planning of content integration learning activities requires that teachers have not only well-developed repertoires of SMK and PCK in one or more of the STEM disciplines, but also well-developed repertoires of trans-disciplinary STEM SMK and PCK (Custer & Daugherty, 2009). Therefore, it is imperative that STEM teacher education should focus not only on the content, foundations, pedagogies, curriculum, research, and contemporary issues of one or more of the STEM education disciplines, but also on the new integrative ideas, approaches, instructional materials, and curriculum implicit in the trans-disciplinary "new" STEM programs (Sanders, 2009).

3.2. Nurturing Situated Theoretical Knowledge

Unfortunately, many current pre-service teacher education programs fail to adequately facilitate the development of situated theoretical knowledge (Beck & Kosnik, 2002; Custer & Daugherty, 2009), a necessary condition for adaptive expertise (Bransford et al., 1999). For example, many pre-service teacher education programs present their students with theoretical knowledge and assume that this will adequately prepare them to acquire practical knowledge in their initial years of practice, leading eventually to a state of expert professional knowledge (Beck & Kosnik, 2002). By contrast, many other programs tend to focus primarily on the mastery of teaching methods and techniques at the expense of developing situated theoretical knowledge (Custer & Daugherty, 2009).

One strategy to address this issue is to focus pre-service teachers' attention on the philosophy/theoretical framework underlying a STEM sequence of learning activities prior to and continually during their working through the activities (Custer & Daugherty, 2009). According to Krajcik (Davis & Krajcik, 2005), this process can be much facilitated by having teachers explore "educative curriculum materials", exemplary units that offer a window through which teachers can glimpse what new strategies look like in action (Loucks-Horsely, Hewson, Love, & Stiles, 1998) and provide models for teachers to follow in developing their own follow-up units. A key design element that makes a curriculum resource "educative" is making pedagogical judgements visible, that is, helping teachers see why particular tasks were applied rather than just directing their actions (Davis & Krajcik, 2005). In this way, teachers move beyond just adding new ideas to their repertoire and learn to make connections between theory and practice that inform their own curriculum designs.

A second strategy is to initiate Lesson Study (Yoshida, 2005) and/or Lesson Plan Study (Cavey & Berenson, 2005) into pre-service teacher education programs. In Lesson Study (LS), small groups of teachers come together as researchers to recursively develop, discuss, teach and systematically reflect on a single lesson over an extended period of time. A variation of this methodology, Lesson Plan Study (Cavey & Berenson, 2005) has been successfully introduced into pre-service teacher education programs in Australia and the US. In Lesson Plan Study (LPS), teams of pre-service teachers come together to recursively plan, discuss and develop a lesson plan. The ultimate purpose of LS and LPS is not to develop a "perfect" lesson; instead it is to yield new ideas about teaching and learning based upon a better understanding of student thinking (Cavey & Berenson, 2005; Yoshida, 2005). LS and LPS situate the construction of theory in a context that is meaningful and relevant to pre-service teachers.

A third strategy that has been proposed is the introduction of cognitive apprenticeship models into pre-service teacher education (Liu, 2005). In cognitive apprenticeship models, pre-service teachers are provided with opportunities to work with and observe how expert teacher(s) deal with problems in an authentic context, and learn how to solve the same or similar problems by "learning-through-guided-experience" in authentic activities (Collins, Brown, & Newman, 1989, p. 457). Through cognitive apprenticeship, pre-service teachers can learn high-level cognitive and metacognitive skills which expert teachers use during instructional planning (Liu, 2005)

A fourth strategy involves the establishment of computer-supported collaborative learning (CSCL) communities (Nason, Chalmers, & Yeh, 2012; Scardamalia & Bereiter, 2003) within STEM pre-service education courses. Discourse within CSCL environments enables the production of shared artifacts such as concrete models, visual representations and experimental set-ups etc. (Scardamalia & Bereiter, 2003). Unlike the artifacts generated in most face-to-face meetings, CSCL-generated artifacts do not disappear at the conclusion of the discussion; online discussions proceed through producing and reflecting on persistent discourse (Goodyear & Ellis 2007). Thus, online shared artifacts provide affordance for collaborative knowledge building of key STEM education theoretical and related practical knowledge that cannot be replicated by face-to-face discussions (Scardamalia & Bereiter, 2003).

3.3. Nurturing Positive Attitudes and Dispositions towards STEM

Addressing many pre-service teachers' fears about and negative dispositions towards "new" STEM curricula and pedagogies needs to be a major focus of STEM teacher education programs (Cunningham, 2009). Two classes of strategies for addressing pre-service teachers' fears and negative dispositions about STEM emerges from the review of the literature: *cognitive change strategies* and *affective and cognitive change strategies*.

Cognitive change strategies assume that pre-service teachers' fears can be addressed by focusing on how pre-service teachers learn and understand STEM content knowledge. One such strategy is to align teaching practices in undergraduate STEM courses more closely to reformed student-centred practices. This strategy has been applied in the University of Colorado's reforms in undergraduate physics education where there has been a move away from teacher-centred and passive-student pedagogy to a student-centred, inquiry oriented, discipline-based model of pedagogy that is research-based and research-validated (Finkelstein & Pollock, 2005). This strategy has its basis in two research findings; many pre-service teachers' fears about STEM can be attributed to how STEM subjects are taught in undergraduate courses (Brady & Bowd, 2005), and that faculty teaching STEM content not only influence pre-service teachers' understanding of STEM content, but also provide models for how STEM subjects should be taught (McGinnis, Watanabe, & McDuffie, 2005).

Affective and cognitive change strategies such as *therapeutic intervention* and *bibliotherapy* assume that in order to address pre-service teachers' fears, one needs to focus on *both* cognitive and emotional factors. Therapeutic intervention (Namukasa, Galanidis, & Cordy, 2008/2009) is a form of intervention that is targeted at a whole group rather than at individual pre-service teachers (Hembree, 1990). One example of therapeutic intervention is Namukasa et al. (2008/2009) "warm mathematics" program in which pre-service teachers engage in the exploration of non-routine problems to change how they feel and think about mathematics. Namukasa et al. have found that doing "warm mathematics" offers pre-service teachers the opportunity to (re)-experience and to feel positively about learning mathematics.

Bibliotherapy can be defined as the guided reading of other persons' problems in order to gain understanding or solve problems relevant to one's own therapeutic needs (Wilson & Thornton, 2005). The reader identifies with the protagonist in the stories, but feels safe because they are not the one experiencing the problem. Readers interpret through the lens of their own experiences. For example, Wilson and Thornton got teachers to write reflections on and discuss two research papers that reported on how school children feel about mathematics and about themselves as they learn mathematics and gave a broad overview of the difficulties that primary school students have in learning mathematics. They found that this triggered improvements in pre-service primary teachers' self-image.

4. Framework for Reforming Preparation of STEM Teachers

From the review of the literature, we have generated a framework consisting of a set of three principles and eight strategies for implementing these principles (see Figure 1). Principle 1 focuses on the development of both within-discipline and trans-discipline SMK and PCK. Principle 2 focuses on the development within pre-service STEM teachers of situated theoretical SMK and PCK necessary for the attainment of adaptive expertise. Principle 3 focuses on addressing most pre-service teachers' fears and negative dispositions about teaching STEM.

The operationalization of Principle 1 calls for the inclusion within teacher preparation courses of subjects that facilitate both context and content integration (Strategies A and B). The implementation of Strategies A and B has three important implications for pre-service teacher education courses. First in the need for the inclusion of specific science, technology and mathematics education subjects within the courses. Second is the need for these discipline-based pre-service teacher education subjects to facilitate the pre-service teachers' development of lateral curriculum knowledge (Ball, Thames, & Phelps, 2008) – knowledge of the curriculum being taught in the other STEM disciplines. Third is the need for the inclusion of specific trans-disciplinary STEM subjects where pre-service teachers explore the pedagogy underlying the design and implementation of STEM learning activities where students work on what Brown (2006) refers to as systemic problems – problems that can't be addressed by any one STEM specialty and that engender multiple ways of knowing.

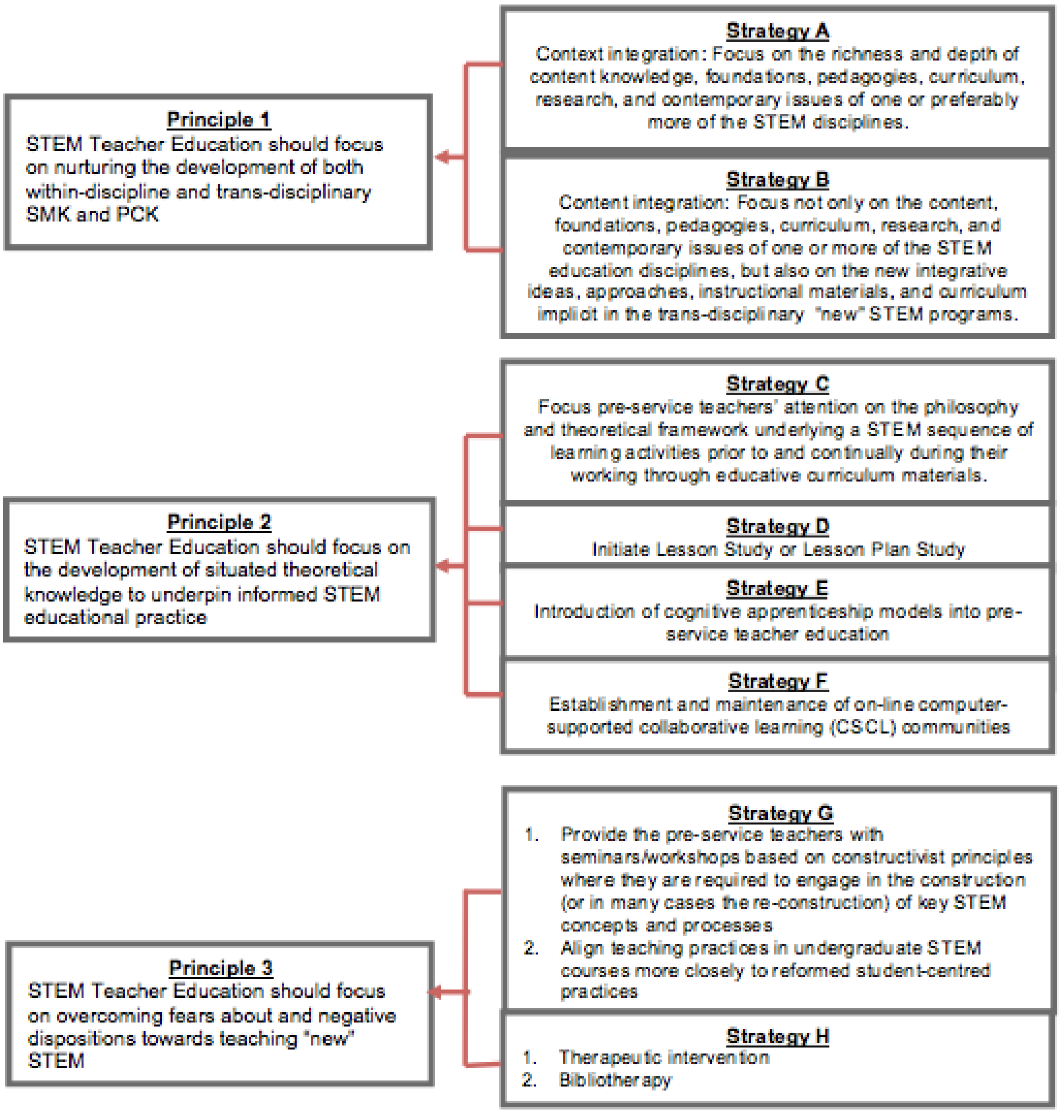

Figure 1. Framework for informing the reform f STEM pre-service teacher education.

The operationalization of Principle 2 calls for the focus on the philosophy and theoretical frameworks underlying STEM learning activities in all discipline-based and trans-discipline-based subjects throughout the whole course of STEM pre-service teacher education programs. Strategies D, E and F suggest the means for the programs to achieve this goal.

The operationalization of Principle 3 calls for the utilization of strategies within STEM pre-service teacher education programs that hopefully not only overcome many pre-service teachers' fears and negative dispositions towards the teaching of STEM but also the development of positive attitudes and dispositions towards teaching within the domain of STEM discipline and trans-discipline subjects.

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