Learning at the Boundaries

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This paper reports on a project that aims to foster interdisciplinary collaboration between mathematicians and mathematics educators in pre-service teacher education. The project involves 23 investigators from six universities. Interviews were conducted with selected project participants to identify conditions that enable or hinder collaboration, and to identify learning mechanisms at the boundaries between disciplinary communities. A hybrid narrative constructed from the interviews is used to illustrate *transformation* as a learning mechanism that leads to new practices.

Introduction

In Australia, as in many other countries, pre-service teacher education programs are structured so that future teachers of mathematics and science typically learn the *content* they will teach by taking courses in the university's schools of mathematics and science, while they learn *how to teach this content* by taking content-specific pedagogy courses in the school of education. Such program structures provide few opportunities to interweave content and pedagogy in ways that help develop professional knowledge for teaching. A suite of Australian government funded projects is addressing this problem by developing and disseminating new interdisciplinary approaches to mathematics and science pre-service teacher education. This paper reports on preliminary findings from one of the projects – *Inspiring Mathematics and Science in Teacher Education* (IMSITE). The overarching aims of the project are to: (1) foster genuine, lasting collaboration between the mathematicians, scientists, and mathematics and science teacher educators who prepare future teachers and (2) identify and institutionalise new ways of integrating the content expertise of mathematicians and scientists and the pedagogical expertise of mathematics and science teacher educators. The first aim provides the focus for this paper, which explores the potential for learning at the boundaries between disciplinary communities of mathematicians and mathematics educators.

Project Context and Overview

The three-year (2014-2016) IMSITE project is being undertaken by 23 investigators in six universities who are collaborating to develop, test, and evaluate the following approaches:

(a) recruitment and retention strategies that promote teaching careers to undergraduate mathematics and science students;

(b) innovative curriculum arrangements that combine authentic content and progressive pedagogy to construct powerful professional knowledge for teaching;

(c) continual professional learning that builds long term relationships with teacher education graduates, enabling them continually to renew their professional and pedagogical knowledge of mathematics and science.

Three universities are located in state capital cities and three in regional cities. Each university's project team comprises at least one discipline professional (mathematician, scientist) and one education professional.

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A feature of the IMSITE project approach is its emphasis on diversity. It is not the intention to promote a single model of pre-service teacher education that privileges one structure for degree programs, one way of combining content and pedagogy, or one form of collaboration between discipline and education professionals. In the project's first year, each participating university committed to implement at least one strategy that had already been piloted or tentatively formulated before the project began (see Table 1 for examples). In the second year, the core group of six universities is engaging with a new group of universities to adapt and transfer strategies to new institutional contexts. The third year will be taken up with preparation of case studies of implementation, analysis of survey and interview data collected from project participants, and development of implementation guides to support engagement and transfer of project outcomes to other contexts.

Table 1
Example Teacher Education Strategies Implemented in Year 1

Priority	Strategies
(a) Recruitment and retention	Design courses that provide a taste of education studies to mathematics, science, and engineering undergraduates.
(b) Innovative curriculum arrangements	Design courses that integrate mathematics content and pedagogy, co-taught by a mathematician and a mathematics teacher educator.
(c) Continuing professional learning	Conduct a pre-service teacher education alumni conference to connect current students, graduates, teachers, teacher educators, and mathematicians.

One of the intended outcomes of the project is the development of diverse models of pre-service teacher education that are adaptable to different institutional contexts. This could be viewed as the *product-oriented* outcome of the project. However, an equally important *process-oriented* outcome is concerned with identification of principles for fostering new forms of collaboration between discipline professionals (mathematicians and scientists) and education professionals (mathematics and science teacher educators). The conceptual framework for this latter aspect of the project draws on Wenger's (1998) social theory of learning, and in particular the notions of communities of practice and boundary practices, to understand how the perspectives of mathematicians, scientists, and teacher educators in these fields can be coordinated and connected. At the time the project began, there were few known instances of productive collaboration in the design and delivery of pre-service mathematics and science teacher education programs in Australia, even though it has been argued that both discipline professionals and education professionals have an important role to play in the preparation of teachers (Hodgson, 2001).

The IMSITE project aims to promote strategic change in teaching and learning in the Australian higher education sector. However, the project has also been designed to contribute to a long-term research program that conceptualises learning from a sociocultural perspective (see Goos, 2014). The research program has investigated the learning of school students and teachers (Goos, 2004; Goos & Bennison, 2008), and it is now being extended to explore opportunities to learn through the exchange of expertise across disciplinary boundaries in mathematics education.

This paper is concerned with interactions between the mathematicians and mathematics educators in the project team. Aligned with the first aim of the project – fostering interdisciplinary collaboration – the paper addresses the following research questions:

1. What conditions enable or hinder sustained interdisciplinary collaboration?
2. What learning mechanisms are emerging at the boundaries between communities?

Learning Within, and Between, Communities of Practice

Wenger (1998) argued that learning involves participating "in the *practices* of social communities and constructing *identities* in relation to those communities" (p. 4, original emphasis). He identified *practice* as contributing to the coherence of a community, and described three dimensions of communities of practice: mutual engagement of participants, negotiation of a joint enterprise that coordinates participants' complementary expertise, and development of a shared repertoire of resources for making meaning.

Mathematicians and mathematics educators are members of related, but distinct, communities of professional practice, and it is a fundamental premise of the IMSITE project that connecting the communities is essential to achieving a seamless, meaningful, and rigorous academic preparation for pre-service teachers of mathematics. Wenger (1998) wrote of *boundary encounters* as potential ways of connecting communities. Boundary encounters are events that give people a sense of how meaning is negotiated within another practice. They often involve only one-way connections between practices, such as one-on-one conversations between members of two communities. However, a two-way connection can be established when delegations comprising several participants from each community are involved in an encounter. Wenger suggested that if "a boundary encounter – especially of the delegation variety – becomes established and provides an ongoing forum for mutual engagement, then a practice is likely to start emerging" (p. 114). Such *boundary practices* then become a longer-term way of connecting communities in order to coordinate perspectives and resolve problems.

There is an emerging body of research on learning mechanisms involved in interdisciplinary work on shared problems. This type of work is becoming increasingly important because of growing specialisation within domains of expertise that requires people to collaborate across boundaries between disciplines and institutions. Akkerman and Bakker's (2011) review of this research literature emphasised that boundaries are markers of "sociocultural difference leading to discontinuity in action or interaction" (p. 133). Boundaries are thus dynamic constructs that can shape new practices through revealing and legitimating difference, translating between different worldviews, and confronting shared problems. As a consequence, boundaries carry potential for learning.

Akkerman and Bakker (2011) identified four potential mechanisms for learning at the boundaries between domains. The first is *identification*, which occurs when the distinctiveness of established practices is challenged or threatened because people find themselves participating in multiple overlapping communities. Identification processes reconstruct the boundaries between practices by delineating more clearly how the practices differ: discontinuities are not necessarily overcome. A second learning mechanism involves *coordination* of practices or perspectives via dialogue in order to accomplish the work of translation between two worlds. The aim is to overcome the boundary by facilitating a smooth movement between communities or sites. *Reflection* is nominated as a third learning mechanism that is often evident in studies involving an intervention of some kind. Boundary crossing – moving between different sites – can promote reflection on differences between practices, thus enriching one's ways of looking at the world. The fourth learning mechanism is described as *transformation*, which, like reflection, is found in studies investigating effects of an intervention. Akkerman and Bakker state that transformation is a learning mechanism that can lead to a profound change in practice, "potentially even the creation of a new, in-between practice, sometimes called a boundary practice" (p. 146). They go on to label processes of transformation as including:

- Confrontation – encountering a discontinuity that forces reconsideration of current practices;
- Recognising a shared problem space – in response to the confrontation;
- Hybridisation – combining practices from different contexts;
- Crystallisation – developing new routines that become embedded in practices;
- Maintaining the uniqueness of intersecting practices – so that fusion of practices does not fully dissolve the boundary;
- Continuous joint work at the boundary – necessary for negotiation of meaning in the context of institutional structures that work against collaboration and boundary crossing.

Akkerman and Bakker note that, although transformation is rare and difficult to achieve, it carries promise of sustainable impact. They also propose that identification and reflection, both of which involve recognising and explicating different perspectives, are necessary pre-conditions for transformation to occur.

While boundary practices might evolve spontaneously, they can also be facilitated by *brokering*. Wenger (1998) explained that the job of brokering is complex because it requires the ability to "cause learning by introducing into a practice elements of another" (p. 109). Bouwma-Gearhart, Perry, and Presley (2012) identified brokering as one of the key interdisciplinary strategies for improving pre-service teacher education in the STEM disciplines in US research universities. They found that successful brokers connect the disciplinary paradigms; they are able to speak the specialised languages of mathematics and science, as well as translate the language and concepts of education research into forms that STEM academics can understand and use. Brokers have the ability to understand and coordinate the expertise that academics from all disciplines can contribute to the task of improving pre-service teacher education.

Research Methods

The IMSITE project is jointly led by a mathematician and a mathematics educator (the author of this paper) from one of the participating universities. In the first year of the project, interviews were conducted with the lead investigators based in the other five universities. In Universities A and B, the lead investigators were a mathematician and a mathematics educator, who were interviewed together. In Universities C and D, the lead investigator was a mathematician, and in University E a mathematics educator. The interview for University A was conducted by the two project co-leaders; other interviews were conducted by the lead mathematics educator only. The timing of interviews was arranged to take advantage of events that participants were scheduled to attend. These included the 2014 MERGA conference (June), a project dissemination forum (September), and the *Connections and Continuity* conference organised by the Australian Association of Mathematics Teachers and the Australian Council of Deans of Science to explore the transition in the study of mathematics from school to university (December). Table 2 summarises information about the interview timing and participants.

Interviews were semi-structured to allow for consistency in the topics of inquiry and flexibility in the depth and sequencing of questions. Question prompts included:

- To what extent is there interdisciplinary collaboration between mathematicians and mathematics teacher educators in your university?

- Can you describe any barriers to, and enablers of, such collaboration?
- What types of exchanges and activities that bring together mathematicians and mathematics educators do you consider to be most successful?
- Do you know of any people who act as brokers of interdisciplinary collaboration? What brokering activities do they successfully use? What are their characteristics that make them effective brokers?

Table 2
Interview Timing and Participants

Date	University	Mathematician	Mathematics Educator
September	A	*	*
December	B	*	*
December	C	*	
December	D	*	
June	E		*

Interviews lasted from 20-40 minutes; they were audio-recorded and later transcribed. Analysis of the interviews was guided by the two research questions listed earlier. To answer question (1), regarding enabling/hindering conditions, a content analysis of transcripts identified relevant excerpts and developed a minimal set of categories that allowed similarities and differences in the responses to be highlighted. This part of the analysis was therefore inductive, in moving from data towards principles for developing interdisciplinary collaboration. To answer question (2), regarding emergence of learning mechanisms at the boundary between disciplinary communities, the transcripts were scrutinised for evidence of the mechanisms theorised by Akkerman and Bakker (2011). Supplementary data to address question (2) were drawn from reports presented at a project team meeting in June 2014.

Towards an Understanding of Interdisciplinary Collaboration

What Conditions Enable or Hinder Sustained Interdisciplinary Collaboration?

All participants referred to *personal qualities*, including open mindedness, trust, mutual respect, shared beliefs and values, as being crucial to *enabling* interdisciplinary collaboration. Such qualities allow for productive disagreements and challenges:

> I like the fact that you [mathematician] are challenging what I say, my views of the world. I really value that. Obviously, there's trust there because, I guess, if there wasn't trust I wouldn't be happy. [University B, mathematics educator]

One interviewee (a mathematics educator) identified the importance of having confidence in one's own disciplinary knowledge of mathematics while at the same time being willing to admit ignorance:

> I'm sure that sometimes education people might feel a bit inferior to … mathematicians when they talk to them. Possibly vice versa as well, when they're talking about pedagogy and they [mathematicians] think "I don't know anything about that, that's strange language". So I guess there's that fear of looking like a fool in front of the other, which you've kind of got to get over at some point somehow. [University E, mathematics educator]

A second condition, explicitly mentioned by interviewees from three universities, was identification of a *common or shared problem*. In one case the problem became shared when the mathematician and mathematics educator realised that they could help each other solve problems that were initially unrelated:

> A lot of the stories that X [mathematics educator] told me about what she was facing in terms of challenges with her maths students or the people training to be maths teachers caught my attention; stories of students who weren't capable enough when they were out in the classroom as pre-service teachers. So at that point I knew that I had to put in some effort in terms of meeting X's needs. At the same time X was able to put in effort in meeting my needs because we were having challenges in our first year maths classes around tutorial engagement and that sort of thing. X was able to offer some as a sort of mentoring type of role in an action research project where she was the facilitator. [University A, mathematician]

In other cases, a shared problem was identified when participants recognised that they taught the same pre-service secondary students – "You teach the students maths and I teach them education, we should at least be sharing what we know about the students" (University B, mathematics educator).

A striking *hindrance* to interdisciplinary collaboration, mentioned by interviewees from four universities, was the *physical separation* of the buildings where mathematicians and mathematics educators worked. In one university these disciplines were located on separate campuses, and at the other universities the disciplines were typically on opposite sides of the same campus:

> We are at polar ends of the campus. There's a big gully in between and there is a bridge. So we've got our metaphorical bridge. We alternate weekly meetings between the math and stat side and the education side. So we're walking over to the other side or the other side is coming to us. [University C, mathematician]

A further structural hindrance, identified by interviewees in four universities, was embodied by *workload formulas* or *financial models* that did not recognise or reward interdisciplinary collaboration:

> It's very difficult to get things like what we do [design and teach with a mathematics educator a course on mathematical knowledge for teachers] to be recognised in workload models. We do a lot of things under the radar but we don't actually get acknowledged on our workload. So in a sense we're doing extra stuff. [University A, mathematician]

Despite respectful relationships having been established between the mathematician-mathematics educator pairs who participated in the project, interviewees in three universities referred to entrenched *cultural differences* between the disciplines in their institutions as hindrances to broader collaboration. More often than not, interviewees expressed frustration with the culture of their own discipline:

> It annoyed me when I heard colleagues of mine complain about the other side, the people across the creek. When it came to the science pre-service teachers or the maths pre-service teachers, whatever problems they had, my colleagues blamed the other side. [University A, mathematics educator]

> I think my colleagues are free to let me do whatever I want to do, provide that it doesn't impact on their day-to-day workload and the way they approach what they look to do. So they're very supportive … "but we don't actually care what you're doing". [University B, mathematician]

What Learning Mechanisms are Emerging at the Boundaries between Communities?

Glimpses of some of the learning mechanisms identified by Akkerman and Bakker (2011) emerged during the interviews. The following brief narrative presents a hybrid case constructed from all the interviews. The purpose is not to draw conclusions about boundary practices in any one university, but to illustrate what *transformation* can look like as a mechanism for learning at the boundary between disciplines. (Quotes have been selected from interviews. Names are pseudonyms.)

A mathematician (Carol) is working with a mathematics educator (Tess). Before the IMSITE project began they got to know each other via an externally funded teaching and learning project. Carol was then allocated to the teaching of a first year mathematics subject for pre-service teacher education students. She was surprised by students' apparent lack of mathematical knowledge after having completed 12 years of schooling:

> I was lamenting, "Oh my goodness me, I can't believe they don't know any maths", like they know less that I had anticipated for someone who had come through the Australian schooling system. [Carol, mathematician]

This experience represents a *confrontation*, a kind of discontinuity between the two worlds of school mathematics and university mathematics that prompted Carol to reconsider her current practice as a teacher of university mathematics. Recognising this confrontation led both to explore each other's worlds:

> I learned a lot about how education works and Tess learned a lot about how we function. We broke down some of the scepticism that both sides can have. [Carol, mathematician]

Carol discussed her observations with Tess, who was sympathetic and interested in exploring the differences between teaching mathematics and education in a university environment. Tess remembered "noticing that my pre-service teachers, their content knowledge was not strong", and she pointed out to Carol the areas that she wanted her to focus on in the first year mathematics course. Carol acknowledged that "I was teaching her [Tess's] students at the time", and both thus recognised a *shared problem space* in which both were contributing to the mathematical preparation of future teachers.

Given this problem space, Carol and Tess are working towards a *hybridisation* of practices from their respective disciplinary contexts. The hybrid result is a new mathematics content subject that is jointly planned and taught, as Tess explained:

> We're in the class together, one of us leads and the other acts as a sort of sounding board. We planned the weeks so certain weeks are Carol's weeks and certain weeks are my weeks. [Tess, mathematics educator]

There are encouraging signs that this new hybrid practice will become *crystallised*, or embedded into institutional structures. The teacher education program is under review, and the Heads of Mathematics and Education have invited Carol and Tess to design two new mathematics-specific pedagogy subjects for the revised program. The subjects will be *owned* by Education, with an income sharing arrangement to recognise the teaching contribution from Mathematics.

Despite the success in creating a new hybrid practice, Carol and Tess also *maintain the uniqueness of their established practices* as a mathematician and mathematics educator. Carol acknowledged their complementary expertise when teaching the mathematics subject together:

> We go to class and there are times when she says to me "That's all yours because it's beyond what I understand" and that's fine. Likewise she'll come in and talk about the greats of education and I'm just going blank, no idea. As an educator it comes out very strongly that she's very well practised. [Carol, mathematician]

The collaboration is sustained by *continuous joint work at the boundary* between the two practices. This includes weekly project meetings, attending and teaching into each other's tutorials in mathematics and mathematics education subjects, joint supervision of Honours students, and jointly conducted professional development for practising teachers.

Concluding Comments

Theorising interdisciplinary collaboration in terms of communities and boundary practices makes it possible to conceptualise the boundaries between disciplines as sociocultural differences that are generative of new practices – and, therefore, new learning. This paper has begun to consider what that learning looks like, and what conditions favour or hinder it. Akkerman and Bakker's (2011) classification of learning mechanisms at the boundary, while not a fixed model, does illuminate possibilities that are emerging in the IMSITE project and that could inform the development of future collaborations in other universities. Their review, together with the interview data from the project, also highlights some challenges for sustaining collaboration. One of these is the ambiguous nature of boundaries and the implications for people who work there, especially those who act as brokers between disciplines. As Akkerman and Bakker point out, brokers can feel like they belong to *both* one world *and* the other, or to *neither* one world *nor* the other. This was a challenge articulated by one of the mathematicians who participated in the IMSITE interviews:

> I'm seeing myself more and more in between maths and education, caught a little bit in no man's land so I don't belong to either. I'm not unhappy with that because it's been quite an interesting and exciting mind-opening experience, but I do see that the expertise I'm gaining from being involved in the IMSITE project is not necessarily going to get my career furthered in terms of being a mathematician. [University D, mathematician]

The IMSITE project is providing valuable evidence of learning at the boundary between communities of mathematicians and mathematics educators. It will be important for both communities to support the brokers and boundary crossers who work in this ambiguous space and to acknowledge their innovative role in fostering new practices.

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