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ORIGINAL ARTICLE

Boundary crossing and brokering between disciplines in pre-service mathematics teacher education

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Abstract In many countries, pre-service teacher education programs are structured so that mathematics content is taught in the university's mathematics department and mathematics pedagogy in the education department. Such program structures make it difficult to authentically interweave content with pedagogy in ways that acknowledge the roles of both mathematicians and mathematics educators in preparing future teachers. This article reports on a project that deliberately fostered collaboration between mathematicians and mathematics educators in six Australian universities in order to investigate the potential for learning at the boundaries between the two disciplinary communities. Data sources included two rounds of interviews with mathematicians and mathematics educators and annual reports prepared by each participating university over the three years of the project. The study identified interdisciplinary boundary practices that led to integration of content and pedagogy through new courses co-developed and co-taught by mathematicians and mathematics educators, and new approaches to building communities of pre-service teachers. It also developed an evidence-based classification of conditions that enable or hinder sustained collaboration across disciplinary boundaries, together with an empirical grounding for Akkerman and Bakker's conceptualisation of transformation as a mechanism for learning at the boundary between communities. The study additionally highlighted the ambiguous nature of boundaries and implications for brokers who work there to connect disciplinary paradigms.

Keywords Mathematics teacher education · Boundary crossing · Boundary practices · Brokering · Community of practice · Interdisciplinary collaboration

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Introduction

There is great diversity in the structure of, and approaches to, mathematics teacher education across the world (Tatto et al. 2012). In many countries, however, university-based pre-service teacher education programs are typically structured so that future teachers of mathematics learn the *content* they will teach by taking courses offered by the university's mathematics department, while they learn *how to teach this content* by taking mathematics-specific pedagogy courses within the university's education department. Such program structures provide few opportunities to interweave content and pedagogy in ways that help develop professional knowledge for teaching (Ball and Bass 2000). These structures also make it difficult for mathematicians and mathematics educators to gain mutual understanding of each other's roles in preparing future teachers or to generate a commitment to collaboration in addressing joint problems (Fried 2014). However, the boundaries between disciplinary communities can also carry potential for learning when people encounter discontinuities in interaction and perspectives (Akkerman and Bakker 2011).

This article explores the potential for learning at the boundaries between disciplinary communities of mathematicians and mathematics educators in pre-service teacher education. It draws on data from the *Inspiring Mathematics and Science in Teacher Education* (IMSITE) project, one of a suite of large-scale national projects funded by the Australian Government with the purpose of driving

> a major improvement in the quality of mathematics and science teachers by supporting new pre-service programs in which faculties, schools or departments of science, mathematics and education collaborate on course design and delivery, combining content and pedagogy so that mathematics and science are taught as dynamic, forward-looking, and collaborative human endeavours. (Department of Education and Training 2016)

The IMSITE project aimed to achieve the purposes outlined above by (1) fostering genuine, lasting collaboration between mathematicians, scientists, and mathematics and science educators who prepare future teachers and (2) identifying and institutionalising new ways of integrating the content expertise of mathematicians and scientists (referred to in the project as *discipline academics*) with the pedagogical expertise of mathematics and science educators (referred to in the project as *education academics*). While the project as a whole was concerned with both mathematics and science teacher education, in this article, the focus is on the preparation of mathematics teachers at both primary and secondary levels.

Background

The three-year (2014–2016) IMSITE project was undertaken by 23 investigators in six Australian universities. Each university's project team, comprising at least one discipline academic and one education academic, collaborated 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) Continuing 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

A feature of the IMSITE project approach was its emphasis on diversity. Variations amongst the partner universities in terms of institutional grouping, geographical location (three in state capitals and three in regional areas), initial teacher education program structures, characteristics of the university student population, and characteristics of the students and schools to be experienced by graduating teachers ensured that the outputs of the project would be evaluated and embedded in a diverse range of institutional, geographical, and socioeconomic contexts. In addition, it was 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 academics.

In the first year of the project, each of the six partner universities implemented 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, partner universities selected and implemented a second set of strategies that had been successfully trialled in the previous year by other universities in the project team. In the third year, partner universities were encouraged to work with another institution outside the project team that wished to adapt and implement some of the new teacher education strategies trialled in the first two years of the project. Institutions joining the project in this manner were referred to as *cascade* universities. Through these processes, project approaches and outcomes were progressively adapted, tested, and transferred to new contexts.

One of the intended outcomes of the IMSITE project was to develop models for pre-service teacher education that combine content and pedagogy and are adaptable to different institutional contexts. Such an outcome requires collaboration between discipline academics and education academics, initially within a single institution but that subsequently extends beyond institutional boundaries (e.g. to cascade universities). This could be viewed as the "product-oriented" outcome of the project. However, an

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 educator.
(c) Continuing professional learning	Conduct a mathematics pre-service teacher education alumni conference to connect current students, graduates, teachers, teacher educators, and mathematicians.

equally important “process-oriented” outcome is concerned with identification of principles for fostering new forms of collaboration between discipline academics and education academics. 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 and mathematics educators can be coordinated and connected. At the time the project began, there were few known instances of this kind of productive collaboration in the design and delivery of pre-service mathematics teacher education programs in Australia, even though it has been argued that both mathematicians and mathematics educators have an important role to play in the preparation of mathematics teachers (Barton and Sheryn 2009; Hodgson 2001).

The IMSITE project aimed to promote strategic change in teaching and learning in the Australian higher education sector. However, the project was also designed to make a theoretical contribution to a long-term research program that conceptualises learning from a sociocultural standpoint (see Goos 2014). The research program had previously investigated the learning of school students and teachers from a community of practice perspective (Goos 2004; Goos and Bennison 2008), and through the IMSITE project, it was extended to explore opportunities to learn through the exchange of expertise across disciplinary boundaries in mathematics education.

This article analyses interactions between the mathematicians and mathematics educators in the project team by addressing the following research questions:

(1) What boundary practices emerged between the two communities?
(2) What conditions enabled or hindered sustained interdisciplinary collaboration?
(3) How did learning occur at the boundaries between communities?

The first question aligns with the IMSITE project aim of institutionalising new ways of integrating the content expertise of mathematicians with the pedagogical expertise of mathematics educators. The second and third questions align with the project aim of fostering collaboration between mathematicians and mathematics educators.

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. Because communities of practice evolve over time, they also have mechanisms for maintenance and inclusion of new members. Based on this discussion, it is not difficult to see that university mathematicians and mathematics educators would claim membership of distinct, but related, communities of professional practice. This commonsense conclusion is confirmed by more rigorous analyses of differences between the epistemologies and values of these communities (e.g. Goldin 2003; Thornton 2008).

It was a fundamental premise of the IMSITE project that connecting the communities of mathematicians and mathematics educators 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 literature 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. The concepts of boundary practices and boundary crossing have been used to analyse ways in which people from different professional or cultural backgrounds collaborate in diverse contexts, such as health sciences (e.g. Brown 2013; Oborn and Dawson 2010), emergency services (e.g. Andersson and Lindström 2017), instructional design (e.g. Cremers et al. 2017), teacher professional development (e.g. Akkerman and Bruining 2016), and family-school relations (e.g. Ishimaru et al. 2016). In the field of education, research on boundary crossing has additionally focused on the movement of individuals across the boundaries between domains, for example, when the identities of pre-service teachers shift between those of student and teacher (e.g. Kang et al. 2013) or from vocational practice in a previous career to teaching practice (e.g. Chan 2012).

Akkerman and Bakker's (2011) review of the research literature on boundary crossing 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 world views, 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, so that 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, 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 suggest 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 propose that transformation might include the following processes:

- 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

In developing these ideas further, Akkerman and Bruining (2016) suggested that boundary crossing in each of the four forms identified here can take place at institutional, interpersonal, and intrapersonal levels. Institutional boundary crossing occurs when organisations or units seek exchange and cooperation, perhaps leading to new perspectives on their own practice and opportunities for collaborative work. At the interpersonal level, similar interactions occur between individuals or groups of people from different practices, while at the intrapersonal level, a person simultaneously participates in intersecting practices of multiple communities.

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). The notion of knowledge brokering in complex systems has proven useful in higher education. In this context, Jackson (2003) defined the work of brokering as an intentional and purposeful act in which the broker seeks to work in collaborative and creative ways with people, communities, networks, organisations, ideas, knowledge, and resources to develop something new or change something. Bouwma-Gearhart et al. (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. Boundary encounters between different communities often result in confusion and misunderstanding, and brokers can find themselves in situations of uncertain legitimacy occupying an insider-outsider position on the edges of the communities they seek to connect. Kubiak et al. (2014) suggest that work involving a strong moral purpose—such as educating children and young people—sustains brokers and provides the "glue" for successful boundary encounters (p. 94). Brokering exemplifies the intrapersonal boundary crossing described by Akkerman and Bruining (2016).

In the IMSITE project, connecting mathematicians and mathematics educators both within and across institutions required boundary encounters: firstly, to create a new set of practices within each partner institution by drawing on the expertise of discipline academics and education academics, and then to introduce new practices into the corresponding cascade university. As these interactions involved the joint efforts of members of different communities, they were of the delegation type and also created opportunities for brokering.

Research design and methods

For the purposes of this article, the participants in the research were the mathematicians and mathematics educators who comprised the IMSITE project teams in the partner and cascade universities. To address our three research questions, we collected and analysed data from two sources: interviews and written reports provided annually by each partner university.

Data collection

Interviews were conducted in the first and third years of the project (2014 and 2016). In the first year, the project co-leaders—a mathematics educator (first author of this article) and a mathematician—interviewed the lead investigators in the other five partner 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 jointly conducted by the two project co-leaders; other interviews were conducted by the lead mathematics educator only. The timing of first-year interviews was arranged to take advantage of events that participants were scheduled to attend, such as conferences and project dissemination forums. Altogether three mathematics educators and four mathematicians were interviewed between June and December 2014.

In the third year of the project, a project officer (second author of this article) interviewed a larger sample of mathematicians and mathematics educators from all six partner universities, including the project co-directors (university F), as well as from three cascade universities (universities X, Y, and Z). Between March and December 2016, seven mathematics educators and eight mathematicians from partner universities were interviewed, together with four mathematics educators and two mathematicians from cascade universities. Interviews were conducted either individually or with groups of participants, depending on their availability. As in the first round of interviews, the timing was largely influenced by opportunities to link data collection with other project events such as conferences and forums that were attended by the participants. 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 for the first round of interviews included the following:

Table 2 Interview timing and participants

University	Round 1 (June–December 2014)	Round 2 (March–December 2016)
Partner A	(M + ME)	(M + ME)
Partner B	(M + ME)	M, ME
Partner C	M	M, M, M, M, ME, ME
Partner D	M	(M + ME)
Partner E	ME	ME
Partner F	–	(M + ME)
Cascade X	n/a	M, M, ME
Cascade Y	n/a	(ME + ME)
Cascade Z	n/a	ME

Parentheses indicate group interview

M mathematician, *ME* mathematics educator, *n/a* not applicable. Parentheses indicate group interviews.

- To what extent is there interdisciplinary collaboration between mathematicians and mathematics 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?

Similar questions were asked in the second round interviews, with amendments to take into account the timing in relation to the project activities. Additional questions asked about working with cascade universities:

- How did you identify the cascade university with which you are working?
- What benefits are there to your university's participation in this project as a cascade university?

Interviews lasted from 20 to 40 minutes; they were audio-recorded and later transcribed in full.

Supplementary data were drawn from the written annual reports provided by each partner university that described activities and outcomes mapped against the two project aims of fostering interdisciplinary collaboration and integrating mathematics content and mathematics pedagogy.

Data analysis

Analysis of the data was guided by the three research questions listed earlier. To answer question (1), regarding boundary practices that emerged between the communities of mathematicians and mathematics educators, evidence was initially sought from partner university annual reports describing new models of teacher education that integrated content and pedagogy. Transcripts of interviews with partner university participants were then searched for evidence of exchanges and activities that brought mathematicians and mathematics educators together to work on these initiatives and that subsequently institutionalised new practices. This analysis was carried out by the second author.

For question (2), regarding conditions enabling or hindering interdisciplinary collaboration, the first author carried out an initial content analysis of first round interview transcripts to identify 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. The categories so developed were then applied by both authors to the reading of second round interviews with partner and cascade university participants. The meaning of the categories was refined in this process, but no new categories were deemed necessary and none were modified or deleted.

To answer question (3), on how learning occurred at the boundary between disciplinary communities, the first author scrutinised transcripts for evidence of the mechanisms theorised by Akkerman and Bakker (2011).

Results

The results of our analysis are presented in three sections corresponding to the three research questions.

Emergent boundary practices

New boundary practices emerged in every university, with mathematicians and mathematics educators attending and teaching into each other's tutorials, jointly supervising Honours students, and jointly conducting professional development for practising teachers. Boundary practices led to integration of content and pedagogy in two ways: co-developed and co-taught courses, and approaches to building communities of pre-service mathematics teachers. These initiatives were developed in both primary and secondary pre-service programs; however, the examples we discuss below come from the secondary context.

Co-developed and co-taught courses integrating content and pedagogy Courses that integrate content and pedagogy for pre-service teachers were either further developed or designed and implemented in four of the partner universities. One example is briefly described here.

Reflective Communication in Mathematics was developed and is delivered collaboratively by a mathematician and a mathematics educator from university D to give non-education students an opportunity to explore teaching (e.g. students are enrolled in Bachelor of Engineering, Bachelor of Mathematics, Bachelor of Advanced Mathematics, Bachelor of Arts programs). In addition to coursework, students undertake private mathematics tutoring and participate in a range of mathematics outreach activities that bring secondary school students and their teachers to the university, for example, in "Work like a mathematician" excursions. Intended learning outcomes include demonstrating the ability to analyse one's own understanding of mathematical concepts, demonstrating pedagogical content knowledge to explain mathematical concepts, and demonstrating technical and communication skills to explain mathematical ideas in creative ways. The initial intent of the course was to provide a "risk-free" experience in teaching to students who are not enrolled in a teaching degree, in order to encourage them to consider a future career in this field. However, the mathematician and mathematics educator who delivered the course also recognised unanticipated benefits for pre-service teacher education students who were taking the course as an elective. The mathematician commented:

> We both realised that [these students] had not made the connections between their maths subjects, their pedagogy subjects, and the maths that they were going to be teaching at school. This was the first subject that they'd had where we were talking about both at the same time, taking it further than anything had been taken – like take the syllabus from high school, push it into where it goes to university where they come back and talk about how might you teach it so that you get those outcomes. [mathematician, university D]

Communities of pre-service secondary mathematics teachers At the time the IMSITE project was conducted, pre-service teacher education programs for secondary mathematics teachers typically involved either an undergraduate education degree, a dual degree such as Bachelor of Science/Bachelor of Education (BSc/BEd), or an initial discipline-specific bachelor's degree followed by a one-year Graduate Diploma in Education or a two-year Master of Teaching. The universities participating in the IMSITE project typically offered multiple programs across all of these models. In all models, content and pedagogy are taught in separate courses. In dual degree programs, it is typical for mathematics content courses to be taught first, in the BSc component of the program, and pedagogy courses some years later, in the BEd component. This means that pre-service mathematics teachers take their mathematics content courses together with a much larger group of BSc students who are not planning to become teachers, and they may not even be aware that there are other aspiring teachers in their content classes. The lack of a cohort experience in the early years of a pre-service teacher education program makes it difficult to build a sense of community amongst prospective mathematics teachers and could lead to unwanted attrition. This was a shared problem identified by the mathematician and mathematics educator at university B when they realised that they taught the same pre-service secondary teacher education students:

> Then I think you and I just started chatting one day … and we thought, you know what? You teach the students maths and I teach them education. We should at least be sharing what we know about the students; starting to compare, contrast, talk about issues, retention. We started talking about the fact that we would lose some of them. [mathematics educator, university B]

University B offers a five-year dual degree Bachelor of Science/Bachelor of Education program, where overlap between mathematics and education courses does not occur until the third year of the program. For this reason, the mathematician and mathematics educator participating in the IMSITE project collaborated to create early cohort experiences for pre-service mathematics teachers. For example, in a compulsory first-year mathematics course, rather than randomly mixing mathematics education students in tutorial groups with non-education students, they are allocated together to special tutorials taught by former secondary school mathematics teachers. Regular lunches and social events are also held to bring together later year pre-service students with first-year mathematics students who have not yet begun their education studies, for networking and sharing of experiences. An alumni conference has been held for the past three years where mathematics pre-service teachers nearing the end of their program participate with recent graduates, mathematicians, and mathematics educators in a professional development day. The purpose of all these cohort-building activities is to create a strong sense of mathematics teacher identity and community from the earliest stages of the degree program, and extending beyond graduation.

Conditions enabling or hindering interdisciplinary collaboration

We first consider collaboration between mathematics educators and mathematicians within the same institution and then turn to an example of collaboration between a partner university and a cascade university.

Interdisciplinary collaboration within universities The relationships between local project team members within each partner university had been established over time; consequently, all the lead investigators who were interviewed in round 1 identified *personal qualities* as a key enabling factor for initiating and sustaining interdisciplinary collaboration. The qualities mentioned by participants included open-mindedness, trust, mutual respect, and shared beliefs and values. For example, one of the mathematicians in a partner university that had a history of collaboration between mathematicians and mathematics educators described the shared value of improving student learning outcomes:

> I think largely we [mathematicians and mathematics educators] value the same things. We really want to see the same outcomes. There are shifts in emphasis. Some people are a bit more interested in something a bit researchy and some people are more interested in let's just make it better for the students. [mathematician, university C]

Sharing values did not mean that there were not also opportunities 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. [mathematics educator, university B]

However, resolving issues and working towards common goals relied on the personal qualities mentioned by participants:

> I think because everybody knows we're working towards the same thing and I think when you know you're working towards the same thing it allows you to be vulnerable because you want a similar outcome, you want a positive outcome. To get there sometimes you realise that you have to be able to be vulnerable to say okay this isn't working and then somebody jumps in and said we tried something like this, perhaps maybe you might want to consider that. [mathematics educator, university B]

A *common or shared problem* was a second condition for initiating and sustaining interdisciplinary collaboration that was mentioned by interviewees from three of the partner universities. 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 [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 her needs. At the same time she 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. She was able to offer some support as a sort of mentoring type of role in an action research project where she was the facilitator. [mathematician, university A]

A striking hindrance to interdisciplinary collaboration, mentioned by interviewees at four partner universities, was the *physical separation* of the buildings where discipline academics and education academics worked. In one university, the discipline academics and education academics were located on separate campuses, and at the other universities, they were typically located 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[istics] side and the education side. So we're walking over to the other side or the other side is coming to us. [mathematician, university C]

A further structural hindrance identified by interviewees in four partner 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. [mathematician, university A]

Despite respectful relationships having been established between the discipline academics and educational academics who participated in the project, interviewees in three partner 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. [mathematics educator, university A]

> Then when you're trying to get people from your own school [mathematicians] to accept the other side is another thing. You've got to be able to sit back and go okay let's appreciate this for what it is rather than compare to what we do because it's completely different and there's no point in comparing the two. Just appreciate it for what it is and what it can contribute in the overall picture. [mathematician, university D]

Cultural differences meant that there were additional individual challenges, especially for mathematicians, in working collaboratively in the space between mathematics and education because of what was valued by the discipline. As a result, some interviewees expressed concerns about the effect of working outside their discipline community on career progression:

> I'm seeing myself move more and more in between maths and education, caught a little bit in no man's land so I don't belong in either. I'm not sure where this is going to lead in the future put it that way … but I do see that the expertise that I'm gaining in the IMSITE project is not necessarily going to get me promoted, is not going to get my career furthered in terms of being a mathematician. [mathematician, university D]

> I think if I was younger I'd be a little bit scared to do the things I am … Especially if I don't have tenure, I would be really worried about moving onto pedagogical research inside a non-education department. [mathematician, university B]

The dilemmas expressed by these participants highlight an additional challenge for sustaining collaboration. This challenge arises from the *ambiguous nature of boundaries* and the implications for people who work there, especially those who act as brokers between disciplines.

Interdisciplinary collaboration between universities

Several of the initiatives that had been implemented in partner universities when the IMSITE program began were adapted and transferred to other partner universities, and so there was evidence that interdisciplinary collaboration could extend beyond institutional boundaries. However, these collaborations were based on the common vision and commitment to the project aims that brought the IMSITE partners together. It proved to be more of a challenge for partner universities to share initial teacher education strategies with cascade universities. The case analysed here involves partner university C, located in a regional city, and cascade university X in a capital city about 400 km away. Four mathematicians were interviewed in Rounds 1 and 2: they are labelled C1 and C2 (from the partner university), and X1 and X2 (from the cascade university). One mathematics educator from the cascade university, labelled X3, was interviewed in round 2.

The partner university had a history of collaboration between mathematicians and mathematics educators, both successful and unsuccessful, before the IMSITE project. Boundary encounters of the delegation type appeared to be well established with personal qualities and a shared problem seen as key ingredients for successful collaboration:

> I think we [mathematicians and mathematics educators] have a really strong set of shared values and mostly similar views. Not identical, because we're different people and come from different places. But similar views as to how we can achieve what we think should be done within the program. We've got different perspectives and so we know that from each end of the stick we're going to be wrong on some things. So we work well together to listen to each other and talk to each other. [mathematician C2]

One of the results of collaboration between mathematicians and mathematics educators in the partner university was the development of a new mathematics course. This course was accessible to students irrespective of their mathematics background because it was "really about problem-solving, investigation, discovery, and some frameworks, really which are informed by a lot of maths education" (mathematician C2). The course was compulsory for secondary pre-service teachers and offered as an elective for primary pre-service teachers. A key feature of the course was that it is a blended course with a substantial amount of online supporting material, including videos.

The first challenge in establishing interdisciplinary collaboration across institutions was for the partner university to identify a suitable cascade university:

> We've [partner university] got a bit of a history with them [cascade university]. We were looking at – we had a range of cascade partners, which we were mulling over. We had quite a few initial, exploratory discussions as to what could work … the discussion with them [cascade university] developed … it soon became clear that they were happy to take it on. One of the things we thought about with cascade was that we were having to be flexible about what mode it [the course] appeared in the partner institutions [referring to the cascade university]. Because … not only does it have to be that we're ready to say here is what we think is a good model for doing this stuff but they also have to be ready to receive it. In most cases when you do change things is when you've just reviewed a program or when you've got some external pressure or something like that. [mathematician C2]

A state of readiness existed at the cascade university to introduce aspects of the partner institution's new course into the pre-service primary program and was facilitated by the recent appointment of mathematician X1 who had previously worked at the partner university. Pre-service teacher education programs at the cascade university had been restructured, and the first-year mathematics course in the primary pre-service teacher education program had become the responsibility of the mathematics department. Improving outcomes in pre-service teacher education courses for prospective teachers of mathematics was seen as a shared problem in both partner and cascade universities. Cross-institutional discussions that were initially one-to-one boundary encounters expanded to involve mathematician C2, mathematician X1, mathematician X2, and mathematics educator X3. Mathematicians C2 and X1 acted as brokers to introduce the practices developed in the partner university into the cascade university.

The brokering carried out by mathematician C2 was mainly advisory in assisting to adapt the new mathematics course developed in the partner university so that aspects of this course can be used effectively in the cascade university: "We decided that an initial way to start the collaboration was to actually set up, so that those richer activities in maths for education students, we could set up as a sideline within their program" (mathematician C2). Mathematician X1 had a much more direct brokering role. Although not involved in the development of the new mathematics course, he had been involved in similar practices in other courses offered at the partner university. His role in the cascade university was to trial some of the material developed for the new mathematics course by creating an extracurricular society and offering some of the online aspects of the course as enrichment activities in a course for first-year primary pre-service teachers:

> We're looking to essentially give the material a trial run, see how the cascade students react to it, see if there are any modification to the way we teach this material that need to go ahead, gather feedback on their response, and take that knowledge forward to possible future development of full courses implemented into their degree program. [mathematician X1]

This comment seems to indicate that mathematician X1 saw himself as member of the community of mathematicians at his former partner institution more so than the current cascade university.

Mathematician X2 was responsible for liaison between the cascade university and the partner university and reported little previous collaboration between mathematicians and mathematics educators in her institution: "We have tried, but it hasn't really gone that well", suggesting possible cultural differences between mathematicians and mathematics educators. However, mathematician X2 reported that the head of the mathematics department was keen to initiate collaboration between mathematicians and mathematics educators and, through personal contacts, began discussions with mathematician C1 that ultimately led to the cross-institutional collaboration.

Although the physical separation between the partner university and the cascade university was significant and the issue of workload formulas was apparent, these potential barriers seem to have been overcome by IMSITE project funding:

> At the end of the day it's those people who have got the time and energy to put into this to make it work. Increasingly [in] universities – workload is an issue. We have quite significant workloads, and sometimes if there are projects that aren't formal projects, they're a little harder to get resourced. [mathematics educator X3]

How learning occurred at the boundaries between communities

Glimpses of some of the learning mechanisms identified by Akkerman and Bakker (2011) were revealed during interviews with participants in the partner universities. The following narrative presents a hybrid case constructed from all the first round 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 Round 1 interviews. Names are pseudonyms.)

A mathematician (Carol) was 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 course 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 Carol and Tess 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 worked towards a *hybridisation* of practices from their respective disciplinary contexts. The hybrid result was a new mathematics content course that was 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]

This new hybrid practice eventually became *crystallised*, or embedded into institutional structures. The teacher education program was under review, and Carol—a mathematician—was invited to serve on the School of Education review panel. The heads of Mathematics and Education subsequently invited Carol and Tess to design two new mathematics-specific pedagogy courses for the revised program. The courses are now "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.

Discussion

Internationally, it is rare to find research or teaching collaborations between mathematicians and mathematics educators (Fried 2014). This study has shed some light on how such collaborations can work, and what their outcomes might be. In doing so, it extends our socioculturally oriented research program to contribute new insights into how "opportunities to learn across disciplinary boundaries in mathematics education [might be] created, theorised, and studied" (Goos 2014, p. 451).

The first contribution made by our study is an account of interdisciplinary boundary practices, proposed by Wenger (1998) as a means of stimulating long-term connections between communities of practice. These new forms of engagement between mathematicians and mathematics educators sparked curriculum development and community-building activities in primary and secondary teacher education courses and programs in diverse institutional contexts. The significance attached to these initiatives needs to be understood in the context of institutional barriers to collaboration experienced by the mathematicians and mathematics educators in Australian universities. Many participants commented on the difficulty of gaining recognition for co-taught courses in workload models because these are treated as invisible extra work. They also expressed frustration at financial models that discourage universities from sharing course income between different disciplines. The emergence of boundary practices contributed to overcoming some of these barriers so that workloads and funding were shared between the mathematics and education departments responsible for new courses that integrate content and pedagogy.

The second contribution is an evidence-based classification of conditions that enable or hinder sustained collaboration across disciplinary boundaries. *Within* the partner universities, collaboration between mathematics educators and mathematicians was enabled by personal qualities of mutual trust and open-mindedness, and the recognition of a common or shared problem in improving the preparation of future teachers. There were also instances of collaboration *between* partner universities. This was not a simple process of transferring resources or courses from one institution to another; instead, each university had to recontextualise and transform the approaches originally developed elsewhere to suit its own circumstances. It could be argued that this process of appropriation and transformation was crucial to the embedding of strategies in new contexts because it required a mutually beneficial exchange of knowledge and understanding. There was less evidence of new teacher education strategies being taken up by cascade universities, possibly because of the lack of existing or potential collaborations between academics from the two disciplines. Interdisciplinary collaboration was well established within the partner universities, whereas the collaborations between partner and cascade universities tended to operate within the same discipline only—whether it was mathematics or mathematics education. Figure 1 depicts the collaborations that were observed within and between universities.

Interdisciplinary collaboration was hindered by institutional and cultural barriers that preserve disciplinary silos. Although there was evidence from the project that it was possible to overcome barriers created by workload and financial models, cultural differences might pose a greater challenge because these are grounded in epistemological differences between disciplines (Goldin 2003; Thornton 2008). These differences also have implications for those who work as brokers at the boundaries between disciplines. As Akkerman and Bakker (2011) point out, brokers can feel like they belong to *both* one world *and* the other, or to *neither* one world *nor* the other. Thus, interdisciplinary collaboration can be professionally risky if brokers feel that they lack legitimacy in either of the communities they seek to connect (Kubiak et al. 2014).

The third contribution of the study begins to develop an empirical grounding for Akkerman and Bakker's (2011) conceptualisation of learning mechanisms at the boundary between communities. The learning mechanism of *transformation* was observed at the interpersonal and intrapersonal levels (Akkerman and Bruining 2016), as individuals and groups of people from different communities identified shared problems, began to work

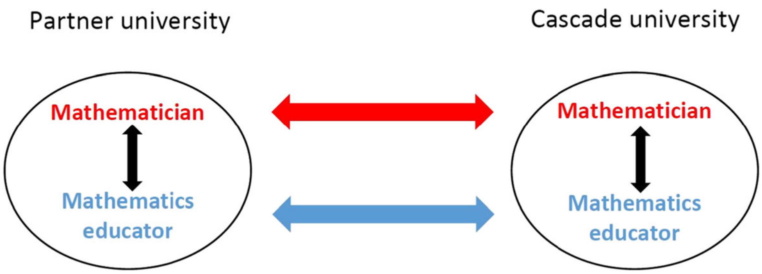

Fig. 1 Observed collaborations within and between partner and cascade universities

collaboratively, and in some cases developed hybridised positions as brokers who connected disciplinary paradigms. 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. Akkerman and Bakker's classification of learning mechanisms at the boundary, while not a fixed model, does illuminate possibilities that emerged in the IMSITE project and that could inform the development of future collaborations in other universities. A limitation of our analysis is that it is based on a hybrid case. Further research, in the way of detailed case studies at several institutions, is needed to more fully explore this mechanism for learning.

Conclusion

The IMSITE project provides an example of how research might bring together mathematicians and mathematics educators with the aim of improving the preparation of future teachers of mathematics. Fried (2014) notes that the fields of mathematics and mathematics education have been moving further apart for many years, as mathematics education research has become more aligned with the social sciences and mathematics research with the exact sciences. Not only do these two fields differ in the kinds of knowledge they generate, they also have different ways of pursuing knowledge. Fried argues that the key to collaboration lies in acknowledging these differences, rather than members of each community trying to "convert" each other to what they cannot be. In the IMSITE project, although there were differences in the nature and extent of interdisciplinary collaboration, it was common for participants to recognise "that each side is looking in the same direction but with very different, complementary eyes" (Fried 2014, p. 15). While the IMSITE project focused on the discipline and education academics who prepare future teachers, it did not systematically investigate the perceptions of the pre-service teachers who experienced interdisciplinary collaboration between mathematicians and mathematics educators. It will be the task of future research to discover how pre-service teachers make sense of the meanings of mathematics and mathematics teaching that they take from the courses developed in the IMSITE project.

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