Learning at the Boundaries: Collaboration between Mathematicians and Mathematics Educators Within and Across Institutions

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Collaboration between mathematicians and mathematics educators may provide a means of improving the quality of pre-service teacher education for prospective teachers of mathematics. Some preliminary findings of a project that investigates this type of interdisciplinary collaboration, both within and across institutions, are reported on in this paper. Interviews were conducted with selected participants to identify the nature of the boundary encounters and brokering involved between disciplinary communities in order to create new practices and transfer these practices to a new institutional context.

The declining participation of Australian secondary students in post-compulsory mathematics in schools and universities (McPhan, Moroney, Cooksey, & Lynch, 2008) has received increased attention because of the need for graduates in Science, Technology, Engineering, and Mathematics (STEM) disciplines. Between 1994 and 2012, participation rates for intermediate level mathematics subjects dropped from 38% to 27% of the Year 12 cohort, and from 16% to 9% for advanced mathematics (Kennedy, Lyons, & Quinn, 2014). One contributing factor may be the difficulties experienced by many secondary schools in recruiting suitably qualified mathematics teachers. Up to 20% of lower secondary school mathematics classes are taught by teachers without tertiary qualifications in mathematics or mathematics teaching methods (McKenzie, Weldon, Rowley, Murphy, & McMillan, 2014). Furthermore, international research has shown that a high proportion of pre-service primary teachers have inadequate understanding of the mathematics concepts they will be required to teach (Senk et al., 2012), possibly leading to increased mathematics anxiety and reduced self-efficacy in teaching mathematics (e.g., Gresham, 2008). While there is no simple solution, improving the quality of teacher education programs is one way in which these issues might be addressed.

The *Inspiring Mathematics and Science in Teacher Education* (IMSITE) project is one of a suite of Australian government funded projects that aim to improve the quality of mathematics and science teachers by promoting and disseminating new interdisciplinary approaches to mathematics and science pre-service teacher education in which content and pedagogy are combined. The IMSITE project aims to: (1) foster genuine, lasting collaboration between mathematicians, scientists, and mathematics and science 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 educators. One of the intended outcomes of the IMSITE project is to develop models for pre-service teacher education that combine content and pedagogy and are demonstrably adaptable to different institutional contexts. Such an outcome requires collaboration between mathematicians and mathematics educators, initially within a single institution but that subsequently extends beyond institutional boundaries. Previously we have reported some preliminary findings on the conditions that enable or hinder interdisciplinary collaboration and the type of learning mechanisms that were emerging at the boundaries between communities of mathematicians and mathematics educators within single institutions (Goos, 2015). In this paper we investigate some of the

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factors that influence collaboration across institutions when innovative practices developed in one institution are trialled in a second institution. Therefore, this paper is aligned with the second aim of the project – institutionalising new ways of integrating the expertise and mathematicians and mathematics educators – and provides a preliminary response to the following research question: What conditions enable or hinder sustained interdisciplinary collaboration across institutional contexts?

Background

The IMSITE project is being undertaken over three years (2014-2016) by 23 investigators in six universities. A mathematician and mathematics educator (the second author of this paper) from one of the participating universities jointly lead the project. There is variation amongst the universities in terms of institutional grouping, geographical location (three are located in capital cities and three in regional areas), pre-service teacher education program structures, characteristics of the university student population, and characteristics of the students and schools to be experienced by graduating teachers. Therefore, a feature of the IMSITE project is its emphasis on diversity with no single model of pre-service teacher education privileged over other possible approaches.

In the first year of the project each of the participating universities implemented at least one strategy that had been piloted or tentatively formulated before the project began. For example, at one participating university a course that integrates mathematics content and pedagogy was designed and co-taught by a mathematician and a mathematics educator. During the second year of the project, the six core universities (*partner universities*) began engaging with a new group of universities (*cascade universities*) so that effective strategies could be adapted and transferred to new institutional contexts. The third year of the project will include sub-projects within cascade universities, analysis of survey and interview data collected from project participants, and the development of implementation guides to support engagement and transfer of project outcomes to other institutional contexts.

The IMSITE project aims to improve the preparation of mathematics and science teachers by promoting strategic change in the design and delivery of pre-service teacher education programs. As well as developing diverse models of pre-service teacher education that are adaptable to different institutional contexts, this involves fostering new forms of collaboration between discipline professionals (mathematicians and scientists) and education professionals (mathematics and science educators) within partner universities and then extending these forms of collaboration to cascade universities. This aspect of the project draws on the notions of communities of practice and boundary practices (Wenger, 1988) to understand how certain conditions enable or hinder interdisciplinary collaboration between mathematicians, scientists, and educators in these fields and the learning mechanisms that take place at the boundaries of these communities.

Communities of Practice, Brokering, and Boundary Encounters

Communities of practice (Wenger, 1988) are characterised by *mutual engagement* of participants in a *joint enterprise* that results in a *shared repertoire* of resources for meaning making; thus creating a shared history of learning but also discontinuities with other communities of practice. These discontinuities create boundaries that define membership of each community. However, communities are not isolated as individuals participate in multiple communities and can also act as *broker*s who are able to “make new connections across communities of practice, enable coordination, and – if they are good brokers – open new possibilities for meaning" (Wenger, 1998, p. 109). Thus brokering involves spanning the boundaries that exist between two distinct communities of practice and has been identified as one of the key strategies for improving pre-service teacher education in the STEM disciplines in US research universities (Bouwma-Gearhart, Perry, & Priestly, 2012).

Connections between communities of practice can also be made through *boundary encounters* in which members of the two communities interact. According to Wenger (1998) these encounters can be one-to-one, effecting the boundary relation between two individuals; can involve immersion of members of one community in the practices of the second community; and can occur through *delegations* where a number of members from each community interact at the same time. As delegations provide a two-way connection between members of distinct communities of practice, this type of boundary encounter can become established and has potential to result in "an ongoing forum for mutual engagement" (Wenger, 1998, p. 114) and the emergence of new practices. These boundary encounters become a means for connecting communities in a sustainable way so that they can coordinate perspectives and resolve problems. Brokers can facilitate boundary encounters by linking practices of different communities and "cause learning by introducing into a practice elements of another" (p. 109).

One of the aims of the IMSITE projects is to bring together the expertise of mathematicians and mathematics educators who are members of related, but distinct, communities of practice in order to develop a range of practices that improve the academic preparation of pre-service mathematics teachers. Connecting mathematicians and mathematics educators both within and across institutions requires boundary encounters: firstly to create a new set of practices within each partner institution by drawing on the expertise of mathematics and education professionals, and then to introduce new practices into the corresponding cascade university. The IMSITE project provides opportunities for boundary encounters between mathematicians and mathematics educators both within and across institutions. As these interactions involve the joint efforts of members of different communities they are of the delegation-type and are also facilitated by brokers. The purpose of this paper is to provide a preliminary exploration of the boundary encounters in one of the partner universities and the corresponding cascade university both within and across institutional contexts.

Research Methods

The research design included interviews with the lead investigators based in each of the partner universities at two points during the project: during the first year (Round 1) and towards the end of the project (Round 2). The Round 1 interviews were conducted by the lead mathematics educator; with one interview conducted jointly by the two project co-leaders. Interviews were conducted with a mathematician, a mathematics educator, or both a mathematician and a mathematics educator depending on the project leadership in each partner university. The timing of interviews was arranged to take advantage of events that participants were scheduled to attend (see Goos, 2015 for further details about the first round of interviews). The lead mathematics educator and a research officer (the first author of this paper) are currently using a similar approach to identify interviewees and conduct the Round 2 interviews. Interviews with project leaders in cascade universities are included in this round of interviews.

The analysis presented in this paper draws on data that were collected from mathematicians and mathematics educators in one of the partner universities and the corresponding cascade university. The partner university was located in a regional city and the cascade university in a capital city about 400 kilometres away. The mathematician from the partner university who participated in a Round 1 interview was on leave when the Round 2 interviews were conducted so the mathematician who had taken on the role of lead investigator in this university was interviewed. Two mathematicians and a mathematics educator from the cascade university were interviewed, selected because of their respective roles in the project (see Table 1). Interviewees from the cascade university were interviewed separately due to their limited availability.

Table 1
Participants in Each Round of Interviews

Interview Round	University	Mathematician	Mathematics Educator
Round 1	Partner	Mathematician A	
Round 2	Partner	Mathematician B	
Round 2	Cascade	Mathematician C	Mathematics Educator A
		Mathematician D	

Interviews were semi-structured to allow for consistency in the topics of inquiry and flexibility in the depth and sequencing of questions. Question prompts were similar to those used in Round 1 interviews but amended to take into account the timing of this round of interviews and included:

- To what extent is there the interdisciplinary collaboration between mathematicians, scientists, and educators in your university?
- 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?
- Can you describe any barriers to, and enablers of, such collaboration?
- Do you know of any people who act as brokers of interdisciplinary collaboration? What brokering activities do they successfully use? What are the characteristics that make them effective brokers?

The duration of interviews was between 20 and 45 minutes; they were audio-recorded and later transcribed.

A content analysis of transcripts from Round 2 interviews was used to identify excerpts that corresponded to the set of categories developed through the analysis of Round 1 interviews (see next section for details of these categories). This analysis was compared to the findings reported previously (Goos, 2015) in order to ascertain if conditions that enable and hinder interdisciplinary collaboration across institutions are similar to, or different from, those that influence interdisciplinary collaboration within institutions. In addition, instances of *boundary encounters* and *brokering* were identified.

Interdisciplinary Collaboration Within and Across Institutions

Interdisciplinary collaboration within institutions between the mathematicians and mathematics educators who were leaders in the project seemed to be enabled by *personal qualities*, and the identification of *a common or shared problem*. On the other hand, these collaborations appear to be hindered by *physical separation* of mathematicians and mathematics educators, lack of recognition or reward for interdisciplinary collaboration in *workload formulas*, and *cultural differences* that exist both within and between the disciplines of mathematics and mathematics education (Goos, 2015).

Developing a new set of practices through interdisciplinary collaboration

The partner university had a history of collaboration between mathematicians and mathematics educators, both successful and unsuccessful, prior to the IMSITE project even though mathematics and education were in different faculties. *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 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 interest in let's just make it better for the students. (Mathematician A)

The comments were echoed by Mathematician B:

> 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 B)

One of the results of collaboration between mathematicians and mathematics educators in the partner university was the development of a new mathematics course:

> We [mathematicians] see it as a maths course. It's not a maths education course. It's a maths course for education students we've developed in collaboration with education colleagues, but it's not co-taught. It's essentially defined by us and they're [mathematics educators] very happy with it. (Mathematician B)

The new course is not content-based and is accessible to students irrespective of their mathematics background because it is "really about problem-solving, investigation, discovery, and some frameworks, really which are informed by a lot of maths education" (Mathematician B). The course is compulsory for secondary pre-service teachers and offered as an elective for primary pre-service teachers. A key feature of the course is that it is a blended course with a substantial amount of online supporting material including videos.

Establishing interdisciplinary collaboration across institutions

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 anything like this, any issues like this 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. They've got to be in a place where they're – in most cases when you do change things is, well when you've just reviewed a program or when you've got some external pressure or something like that. (Mathematician B)

A state of readiness existed at the cascade university to introduce aspects of the partner institutions' new course into the pre-service primary program and was facilitated by the recent appointment of Mathematician C who had previously been 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 B, Mathematician C, Mathematician D, Mathematics Educator A, and another mathematics educator who is yet to be interviewed. Mathematician B and Mathematician C (even though he was now at the cascade university) acted as *brokers* to introduce the practices developed in the partner university into the cascade university.

The *brokering* carried out by Mathematician B seems to be 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 B). Mathematician C has 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 C)

This comment seems to indicate that at this point in time Mathematician C sees himself as member of the community of mathematicians at the partner institution more so than the cascade university.

Mathematician D was responsible for liaison between the cascade university and the partner university and reported little previous collaboration between mathematicians and mathematics educators at the cascade university: "We have tried, but it hasn't really gone that well" (Mathematician D); suggesting possible *cultural differences* between mathematicians and mathematics educators. However, Mathematician D 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 A that resulted in the collaboration between the partner university and the cascade university that is reported on in this paper.

Although the *physical separation* between the partner university and the cascade university seems significant and issue of *workload formulas* is apparent, these potential barriers seems 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 A)

However, this also means that there is pressure to ensure that new practices are sustainable before the end of project funding:

> If we don't have something that ends up being a change that we've made, which stays or being something that we do, we've established, which is sustainable, then we've got to find some – apply for extra money from elsewhere to keep doing it or let it go. (Mathematician B)

While *boundary encounters* across institutions appear to be driven by mathematicians from both universities, there are also boundary encounters within the cascade university as mathematics educators in this university have an advisory role in implementing the new practices:

> Yeah, I'd say probably providing advice … in terms of how we might continue to monitor and evaluate this as well and I think this is a key part of this project. We need to build the monitoring and evaluation framework as well. So, as we do things differently, we can have some confidence that things are going well. (Mathematics Educator A)

Mathematics Educator A sees the design flexibility of the new mathematics course as a key feature from successful implementation: "I think it's one of those – great sort of re-mix, re-use sort of philosophies where you can contextualise this work in another setting, make it make sense, apply it, and that's a significant strength" (Mathematics Educator A). However at the same time, he recognised that there needs to be people in the cascade university who can achieve this, keeping in mind that goals need to be realistic:

> How we tell the story about success will be fundamental, but we need to be realistic as well … there are no quick fixes, and there are no silver bullets – all those sort of ideas. So we need to be realistic about what we can change. (Mathematics Educator A)

Concluding Comments

Communities of practice and the associated concepts of brokering and boundary encounters (Wenger, 1988) provide a means of theorising interdisciplinary collaboration both within and across institutions. Interdisciplinary collaboration within the partner institution appears well established with ongoing boundary encounters of the delegation type that have established new practices for teaching mathematics to pre-service teachers. The nature of the new mathematics course meant that, although it was initially developed as a compulsory course for pre-service secondary mathematics teachers, the course could be taken as an elective by pre-service primary pre-service teachers and aspects of the course could be introduced in the cascade university as enrichment activities in a course for primary pre-service teachers or as extracurricular activities through a mathematics society. As all universities have unique institutional contexts, such design flexibility may be a key to developing new practices that draw on the expertise of mathematicians and mathematics educators to improve the academic preparation of those who will be teaching mathematics in primary and secondary schools, especially if these new practices are to be implemented in other institutional contexts.

Interdisciplinary collaboration between the partner university and the cascade university is in its infancy and it remains to be seen how this collaboration will unfold and whether it will extend beyond the life of the IMSITE project. At this point in time, the collaboration is facilitated by the brokering activities of Mathematician B and Mathematician C and is reliant on project funding. The sustainability of new practices in the cascade university will depend on how much is achieved in this first year and how successful the brokering activities of Mathematician C are in subsequent years. Interdisciplinary collaboration between mathematicians and mathematics educators in the cascade university is new but developing. Such collaboration is likely to be needed if the new practices that have been introduced from the partner university are to be more fully adapted to the new institutional setting.

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