Research in Science Education
https://doi.org/10.1007/s11165-018-9789-5

'Across the Divide': Developing Professional Learning Ecosystems in STEM Education

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Published online: 06 December 2018

Abstract
This paper reports the findings from a cross-sector research project designed to question how the development of university-school partnerships can influence university academics' pedagogic practice in Science, Technology, Engineering and Mathematics (STEM). Findings from this research are offered at time when, in parallel with countries around the world, universities and schools in England are being encouraged to review and reflect on the quality of teaching and professional development, in line with the Teaching Excellence Framework consultation (2016) and the Standards for Professional Development (Department for Education 2016b) (Bianchi 2017). This paper seeks to develop a coherent response to two major issues; the policy imperative to develop greater *science* expertise in schools and to improve the quality of teaching and learning of science in higher education institutions. The research seeks to advance the notion of critical reflection on the quality of cross-sector STEM teaching and learning, by moving to what the OECD (Organisation for Economic Co-operation and Development) (2015, p.15) terms a "'meso' networked level" of professional development in STEM education. This paper highlights how interpreting the imperative of constant change in education reform as a relational, outward looking endeavour offers the potential to help both universities and schools to better address the global education challenges that lie ahead.

Keywords University-school partnership · Professional learning · STEM education · Relational approach

Introduction

For decades, the concept of the *knowledge economy* has informed education policy around the world. Science, Technology, Engineering and Maths (STEM) education is considered a vital

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component in ensuring economic prosperity (Gough 2015; Murphy et al. 2018; The Royal Society 2014; UNESCO 2015) and, as a result, countries across the globe have allocated large amounts of funding to the development of teaching and learning in this field. In a knowledge economy, education, and STEM subjects in particular, are viewed as "the new currency by which nations maintain economic competitiveness and global prosperity" (Duncan 2010). However, there are increasing calls for education policy makers and practitioners to look beyond the focus on improved standards in the teaching and learning of STEM subjects. Research conducted by the OECD (Organisation for Economic Co-operation and Development) (2015) suggests that in considering how best to reform education to meet the needs of a knowledge economy, education institutions need to rethink traditional, formal models of separate institutional learning environments and move instead towards 'learning eco-systems' in education, described as:

> interdependent combinations of different species of providers and organisations playing different roles with learners in differing relationships to them over time and in varying mixes…not a "system level" but a complex series of interlocking systems (OECD 2015, p.17).

There is, therefore, a twofold issue that emerges from the current education landscape: the need to improve STEM teaching and learning and an increasing acknowledgement that our education systems need to adapt and change in order to respond to rapid global shifts in economic and technological development, moving from a landscape of distinctly different and clearly boundaried education institutions towards the creation of more flexible cross-sector ecosystems of teaching and learning. This paper illuminates the process of developing professional learning relationships that aim to do just that.

This article starts by outlining the research purpose and perspective of the study, before contextualising the research in terms of the specific school and university contexts for STEM educators in England, and how education policy change has impacted on teaching and learning in these different sectors. Next, the article outlines the research approach for the project, suggesting that there may be a way to "do Continuing Professional Development (CPD) differently" in order to meet the cross-sector STEM teaching and learning needs of schools and universities. Finally, this article shares the findings of the research project and concludes by considering the implications of these findings for professional development in STEM education.

Research Purpose and Perspective

This article is based on findings from a qualitative research project which set out with the broad objective to explore how university-school partnerships can influence university academics' pedagogic practice in STEM education. The three education sectors in this study (primary, secondary, and higher education) were brought together by the Science and Engineering Education Hub (SEERIH), based at The University of Manchester. Although working from within the university, the hub is unusual in that it is staffed by primary, secondary, and higher education staff with expertise in teacher professional development, curriculum innovation, and research. As such, the hub forms a network of specialists with differing expertise in STEM education, working together to "offer the connectors through

which knowledge passes and ultimately collaborative action takes place" (OECD 2015, p.73). In this way SEERIH has the potential to bridge the divide between the sectors and design and broker cross-sector professional learning opportunities for educators both within, and external to, the university. This thinking corresponds with the ethos advocated by the OECD (2015) and the pressing need for countries to develop learning that is fit for the demands of a knowledge society. The OECD (2015) advocates a more collaborative, cross sector approach to teaching and learning, referring to the need to develop *learning eco-systems* in education:

> It is not about neglecting schools and their organising systems but rather integrating them into more comprehensive concepts and systems. All this entails that we should be thinking of learning ecosystems – interdependent combinations of different species of providers and organisations playing different roles with learners in differing relationships to them over time and in varying mixes (OECD 2015, p.17).

The study set out to provide a space in which educators were able to reflect on and discuss practice and pedagogy in a bid to prompt and scaffold reflection-on-practice (Schön 1983). The project's aims were to lay the foundation stones for a professional *learning eco-system* (Hannon 2009; OECD 2015) in STEM education by:

- brokering learning opportunities between leading secondary and primary schools and the University of Manchester
- engaging academics and teachers in opportunities for knowledge exchange and discussion about STEM pedagogy and practice.
- identifying the similarities and differences between university and school STEM provision, exploring the implications for student transition and approaches to teaching and learning in the university and in schools.
- Stimulating critical reflection within the University and school settings about the fitness for purpose of STEM courses and delivery for twenty-first century learners

In addition, this research deliberately challenges the tendency for university-school partnerships to adopt what Greany et al. (2014, p.6) term "a hierarchical approach in which the university dominates and practitioner knowledge is devalued." In seeking alternatives to universities doing to schools, theoretically, this paper is framed by the concept of a relational approach to engagement as espoused by Warren et al. (2009). Warren et al. (2009) define a relational approach to engagement as a school and its stakeholders getting things done collectively, starting from the point of their "shared interest in advancing the education and well-being of children" (Warren et al. 2009, p.2213).

The Research Context: New Lived Realities in University STEM Education

The research is framed by recent changes in education policy that impact on the teaching and learning of STEM subjects in English schools and universities. The current educational landscape in England places high stakes accountability measures on schools, universities, senior leaders and teachers, driven by government inspection regimes in schools and the introduction of assessment of teaching quality in universities through the Teaching Excellence Framework (TEF):

> The Teaching Excellence and Student Outcomes Framework (TEF) has been introduced by the Government in England to recognise and encourage excellent teaching in universities and colleges. It is intended to help students choose where to study, by providing clear information about teaching provision and student outcomes…TEF is a voluntary scheme, designed for universities and colleges in England, but those in Scotland, Wales, and Northern Ireland are also able to choose to participate. Participating universities and colleges are able to achieve a gold, silver, bronze, or provisional rating…Publicly-funded universities and colleges in England with a TEF award may charge up to the higher maximum tuition fee for 2018 entrants (https://www.ucas.com/undergraduate/what-and-where-study/choosing-course/teaching-excellence-framework-tef-what-you-need-know)

Educational reform based on marketization and notions of consumer choice has resulted in a particular framing of teacher professionalism, what Menter et al. (2010, p.21) refer to as "the effective teacher":

> This model has emerged as the dominant one in much official government discourse across the developed world over the last thirty years. It is closely associated with the economically led view of education that stresses the need for teachers to prepare pupils to take their part in making their respective nations' economies a success (e.g. DfEE 1998). The emphases are on technical accomplishment and on measurement. It is the model for an age of accountability and performativity (Mahony and Hextall 2000).

In England, the paradigm of the effective school teacher is based on achieving standards and competencies and is politically driven, rather than a model of professional development that has been developed by schools and educators themselves. The discourse surrounding the effective teacher will be familiar to school teachers around the world and is particularly pertinent for STEM teachers in all sectors, who are viewed by policy makers as key players in a nation's route to success as a knowledge economy.

However, in reflecting upon approaches to teacher professionalism, a more recent development has been the move towards the effective teacher paradigm in English university education. In England, the higher education sector has previously been dominated by the very different paradigm of the effective academic, where research outputs were taken as the major measure of success. The development of the notion of the effective teacher in university education has developed apace since September 2012, the date when the government enabled English universities to set higher tuition fees of up to £9000 per annum. The introduction of higher level fees for students in English universities has led to a higher education marketplace where students and their families have been repositioned as choosers and consumers. National Student Satisfaction surveys (NSS) have been in place since 2005 and are published and promoted on the Unistats website (https://unistats.ac.uk/) - "the official website for comparing UK higher education course data"—as a way of informing prospective students' choice of university. The NSS results are based on student perceptions of the quality of teaching and learning on their courses, rather than on academic research outputs, and the results so far have not been entirely favourable for universities with high reputations in international research. These developments have been followed by the English government's introduction of the Teaching Excellence Framework (TEF), established to rate universities on their teaching and learning. Moreover, "from 2018 the ratings will determine which universities will be allowed to raise their tuition fees by the rate of inflation" (Adams 2016) and, therefore, which cannot.

The government explains that the TEF assessment will 'focus on outcomes such as student satisfaction, retention rates and employment data' (Gov.uk), stating that:

> The framework will give students clear, understandable information about where the best teaching is on offer and for the first time place teaching quality on a par with research at our universities (Johnson 2016).

New Imaginaries: Identifying Spaces of Possibility to Do Continuing Professional Development Differently

Yet in spite of the challenges and tensions for both the university and school sectors, the current landscape in English education also reveals an interesting space of possibility for *doing Continuing Professional Development (CPD) differently*. Research has clearly identified the need to support primary science teachers and science leaders in the development of their specialist knowledge and confidence levels in teaching STEM subjects (The Confederation of British Industry 2015; Wellcome Trust 2014) and acknowledges that CPD that enables primary teachers to work in collaboration with university academics provides an opportunity to support the development of teacher confidence by helping to build primary teachers' scientific knowledge and awareness of science research and its uses and applications in world settings. However, at the same time, transitioning students from the pedagogic practices of school, where collaborative and student-centred approaches are commonly in use, to the traditional, teacher-centred modes of delivery more often seen in higher education, is a long-standing challenge for universities (European Commission 2013, 2014).

This paper presents the view that CPD that is designed to provide university academics with the opportunity to understand more about current teaching and learning practices in schools has the capacity to stimulate innovation within higher education pedagogic practice. Working with school teachers in this way not only has the potential to support the process of student transition from school to university, but also to have a positive impact on teaching and learning and NSS scores respectively, leading to increased student understanding of and engagement with the STEM subjects and, therefore, helping the future reputation of the university in the English education marketplace. Thus, rather than merely responding to the demands of an audit culture that is driven by discourses "from without…by managers, policy-makers and media" (Stronach et al. 2002. P.130), this project seeks to develop CPD from the "inside out" (Ranson 2003) by starting from the point of view of STEM educators in schools and universities, identifying where cross-sector CPD can help by matching one sector's needs with another's assets.

Whilst professional associations and journals have done much to promote research and rethinking of practice in undergraduate teaching, learning and assessment, little has been written regarding the assets that primary and secondary school teachers can offer to their university colleagues in their professional learning and development. This paper seeks to address this gap in the research. Primary school teachers in particular are widely viewed as being creative and innovative in their teaching practice, with experience in creating *innovative learning environments*. Furthermore, school teachers regularly use active learning and student-centred approaches in their classrooms (OFSTED 2013). It is noteworthy, therefore, that research into STEM teaching and learning in universities has begun to consider how using

active learning, rather than traditional lecturing, impacts positively on students' academic performance (Freeman et al. 2014). The results of Freeman et al.'s (2014) study show that:

> average examination scores improved by about 6% in active learning sections, and that students in classes with traditional lecturing were 1.5 times more likely to fail than were students in classes with active learning (Freeman et al. 2014, p.8410).

Based on their findings, Freeman et al. (2014, p. 8410) suggest that there is a need for a rethinking of approaches to STEM teaching and learning in Higher Education. They state that the findings "support active learning as the preferred, empirically validated teaching practice in regular classrooms" in university STEM education. Moreover, Beach et al. (2012) refer to research published in the United States by The National Research Council (Singer et al. 2012), which "summarized key research findings on effective approaches in college science and engineering courses" (p.53) as being linked to the use of active learning and collaborative work. This type of learning environment, "characterised by the 'buzz' of collegial activity and learning [and] by very active learner voice and agency" (OECD 2015, p.21) is advocated by the OECD (2015) as being an essential foundation stone of teaching and learning across the education sector if nations are to develop the type of knowledge and skills that are required to meet the demands of an ever-changing globalised world. These findings point to the benefits of *doing CPD differently*, providing opportunities for university academics and school teachers to collaborate with the core focus on improving teaching and learning experiences for STEM learners across the school and university sectors.

Methodology

This paper is based on a qualitative research project that set out to explore how the development of school-university professional development partnerships can influence university academics' pedagogic practice in Science, Technology, Engineering and Mathematics (STEM). The expectation was that university academics and teachers would be supported to reflect on and exchange pedagogic knowledge and approaches that would have a positive impact on their teaching and learning practices.

The sample was selected to include university academics and primary and secondary school teachers. Pseudonyms are used to protect the anonymity of the participants. The sample was purposively selected by inviting academics and teachers who had: (a) demonstrated previous interest or engagement in cross-sector STEM CPD initiated by the change agent organisation, or (b) had delivered sessions or participated in some way in the university's school outreach programme, which is facilitated by the university's public engagement team. There were undoubtedly challenges in recruiting participants, due to timetabling pressures and limited dedicated time within work plans for this type of CPD. This was remediated for teachers who benefited from teacher bursaries towards supply cover to enable their release from school responsibilities, a feature that wasn't applicable to academic teaching staff. This, along with the extent of the overall project funds available, resulted in the study being small scale. It is important to acknowledge the limitations of the data at this stage, both as a result of the small sample size and the decision to focus on potential growth points for cross-sector professional learning, and thus the likelihood of participants being supportive of such an approach. However, although acknowledging that there are inherent limitations in such a sampling strategy, the findings present interesting data for policy and practice when considering

alternative approaches to professional development for STEM educators, demonstrating how the adoption of a more relational approach to cross-sector professional learning offers the potential for positive long-term impacts on teaching and learning for students of all ages.

The project was carried out in two phases. Phase 1 consisted of 9 semi-structured interviews with STEM educators: 2 primary school teachers, 2 secondary school science teachers, 4 university STEM academics, and a university outreach coordinator. The interview questions were designed to explore participants' views of STEM teaching and learning in their own setting and their understandings of STEM teaching and learning in other sectors. Phase 2 consisted of an 'immersion' day where 5 university academics were taken to experience STEM teaching and learning in two school settings; one primary school and one secondary school. The day was deliberately structured to engage the participants with teachers from different settings, prompting reflection-on-"cross-sector-practice" (adapted from Schön 1983). Bianchi (2016a, p.2) explains how an immersion event is designed to "provide an initial stimulus and contextualisation" for a programme of professional development, "as opposed to a one-off experience". However, it is important to stress that the immersion event was not designed to be a course that sets out to teach participants how to implement a particular teaching strategy. Instead, the immersion day was designed to facilitate discussion around STEM teaching and learning in HE and its relationship to school practice. Participants shared curriculum models and discussed their day to day STEM teaching and learning practice, whilst lesson observations enabled exploratory enquiry scrutinising the nature of teaching and learning (practice, pedagogy, and philosophy) in university and school settings and allowed a series of professional *learning stories* to emerge in the data.

The participants' reactions to the teaching and learning that they observed were video recorded during the day, and at the end of the day participants were asked to record their critical reflections on the experience in writing. The teachers and academics were asked to focus in particular on anything that they had learned about approaches to STEM teaching and learning that they would like to take back to their own sector or develop further in their own CPD. Each individual's interview and critical reflections were analysed and thematically coded, before then analysing and coding the data for each group together (academics/primary school teachers/secondary school teachers) in order to identify commonalities and differences within the group, before finally comparing and contrasting responses across the different groups to identify overall commonalities and differences. This approach also helped to begin to identify any shifts that had taken place in participants' understanding of their own and others' approaches to teaching and learning as a direct result of observing the realities of STEM teaching and learning in a different setting.

Data analysis thus considered the extent to which the project had prompted academics to reflect on how university-school partnerships could influence their pedagogic practice in STEM education in order to further enhance their students' learning experiences and vice versa for the school teachers. The data also revealed to what extent these professional learning experiences provided 'spaces of possibility' for future cross-sector professional STEM learning communities to work collaboratively in order to improve STEM teaching and learning experiences for all learners, from primary school to university and, in time, lead to opportunities to *co-create* (Bianchi 2016b) new *learning eco-systems* in STEM education as defined by the OECD:

> interdependent combinations of different species of providers and organisations playing different roles with learners in differing relationships to them over time and in varying

mixes…not a "system level" but a complex series of interlocking systems (OECD 2015, p.17).

Following the completion of the two phases of the research, data analysis illustrated the extent to which the project had facilitated the development of professional relationships that could support a) the building of relationships amongst and between different stakeholder groups and b) efforts to bridge the gap in culture and power between university academics and school teachers (Warren et al. 2009), and thus help reposition CPD in STEM education as a collaborative, cross-sector endeavour.

Findings and Discussion

This article focuses on three key findings from the research project, summarised in the table below:

Key findings
1. Repositioning STEM CPD as a relational, cross-sector endeavour has created new possibilities for reciprocal professional learning, which can help to meet the STEM teaching and learning needs of universities and schools.
2. Changing relational identities, with university academics repositioned as 'learners' in schools, generates a different type of professional knowledge exchange about teaching and learning.
3. Using a change agent to bridge cross-sector divisions (a connecting relationship) helps to build collaborative, cross-sector professional learning communities to improve STEM teaching and learning for children and young people.

These findings emerged from the thematic analysis and the quotes included below have been chosen to illustrate the key points. The data shows how adopting a relational approach towards CPD, professional identities and change agents has revealed possibilities for new collaborative relationships, identifying the potential for innovative approaches to knowledge exchange that challenge traditional cross-sector partnerships. Firstly, the findings reveal that repositioning STEM CPD as a relational, cross-sector endeavour presents spaces of possibility for reciprocal professional learning that can help meet the STEM teaching and learning needs of universities and schools. The second finding reveals that providing the opportunity for academics to go into schools as *learners*, rather than *experts*, generated a different type of professional knowledge exchange about teaching and learning, focusing not only on "professional learning" but also "capacity creation" (OECD 2015, p.20) through cross-sector knowledge exchange. Finally, the study highlights the key role of a change agent in bridging the divide between different education sectors in order to build collaborative, cross-sector professional learning communities to improve STEM teaching and learning for children and young people.

Repositioning STEM CPD as a Relational, Cross-Sector Endeavour

Although small-scale, the findings from the interviews in phase 1 of this research project show how an interesting pattern starts to emerge from the data; namely that the strengths of one sector can be matched with the professional development needs of another, suggesting that the

repositioning of STEM CPD as a relational, cross-sector endeavour can offer opportunities to improve STEM teaching and learning for all ages. The participants' interview responses to questions about their professional strengths and areas for development clearly show how the school teachers considered their strengths to be their pedagogical skills and knowledge (for example, assessment for learning and the development of student-centred and collaborative teaching and learning strategies), whilst the academics identified these skills as an area for development within the university sector. In contrast, the academics felt that their strength as STEM educators lay in their subject specialist expertise and their knowledge of working scientifically at higher levels, both in universities and in industry, whilst the school teachers felt that they lacked sufficient knowledge in these areas, affirming the project's belief that there is a need to develop reciprocally supportive, relational engagement in cross-sector CPD. The possibilities for repositioning STEM CPD as a relational, cross-sector endeavour are illustrated in the quotes in this section.

In phase 1, participants were asked to identify areas of their teaching that they wished to develop or change. A common theme that university academics identified as an area for personal professional development was the use of group work with their students, as opposed to the traditional lecture style delivery:

> I suppose one of the main ways is looking at sort of non-traditional ways of engaging with students. The lecturing is one way of getting information across…Doing more group work because that's something that prepares students better for industry. I am looking for ways to develop that as well.
>
> *David, lecturer in Computer Science*

Paul, a lecturer in the School of Electronic and Electrical Engineering, expresses the difficulty he finds in assessing group work:

> some things are very difficult to examine in a practical setting, like team work, group work and separating out individual contributions. Realising that there is a time when it is fine to let students fail, make mistakes and learn from those mistakes, which a lot of people feel desperately uncomfortable with…try and get around the fact that assessment is quite often is pass and fail and we judge success, not on how someone has approached the problem, but on the outcome…we could do a lot more assessment work around their approach to problem solving. We do more practical work than we have ever done before but we could do so much more; we are still not so great with assessment with practical work.

In contrast, when asked about the strengths or expertise she has in teaching science Heather, a secondary school science teacher, identifies group work as the central tenant of her approach to teaching and learning:

> I'm trying to not just give them just content but to develop them as team workers so they can communicate what they are learning about. Have they got the skills to communicate what they know to someone else or lead a team? So [being] team-workers, time-managers…In science it is about building in practicals and activities where they are working together more than working individually - and lots of discussion activities. They like to express their views, so activities where they can do that are a good thing.

Moreover, Heather is confident in her ability to assess her students' progress. Interestingly, she cites building supportive relationships with her students as being fundamental in developing effective assessment of teaching and learning:

> I think I am quite good at assessment. So different ways of seeing how and what progress they are making…the main thing is having relationships with them. Them knowing that you care about them.

However, Jane, a lecturer in Chemistry, refers to the development of relationships with students as a key area for professional development in the university context, particularly concerning traditional notions of academic power and control; indicating an area of interest for further research. In the extract below, Jane explains how some of her university colleagues struggle to move away from teacher-centred approaches, where the lecturer is positioned as 'the expert' and the students 'the novices':

> a big barrier is to redefine expectations and help students come to accept multiple different ways of dealing with their own learning and then there is sort of the staff level barrier, which is your staff who are not necessarily used to thinking about teaching and learning practice. Ideas of being the 'keeper of all knowledge', that we have a position of power and allowing people to move beyond their position of power to allow the students to take that power. So I think that there are different types of barriers. There are barriers and challenges in terms of helping the students. But there are also barriers and challenges in terms of helping my colleagues.

Yet primary school teachers Andrea and Tom say their strengths lie in practical teaching strategies to motivate and engage learners and position teachers as facilitators; strategies such as linking learning to students' personal lives, varying learning activities and maintaining good pace, planning for collaborative learning opportunities and hands on, practical activities, all of which are equally applicable to university settings and could support colleagues like Jane in building CPD to improve teaching and learning and learner satisfaction:

> I think sometimes the way the teacher comes across whether they like science or not always seems to affect the children as well…I try to make it as practical as possible where they are getting to do more things themselves…so I would say the enthusiasm I have for it and wanting the children to work collaboratively with it….trying to link the scientific ideas with the children's personal lives. I always make sure the children have something they can grasp because there are so many abstract ideas to do with science and maths as well that it is hard for them to understand where it comes from. So I do try and make sure that we link that into real life as much as possible.
>
> *Andrea, primary school teacher*

> I think I am quite experienced in managing a class of children to make sure that everybody is with me, everybody is engaged. That's often through pace but it is also developing what's to come, so they are 'wound up', they are keen to get on with what they are doing, they are noticeably excited. But also the meat of the learning is always something concrete, hands- on, textured. Children know that this is coming as well – and that is key to motivation.

Tom, primary school teacher

What is interesting at this point in the data is how the school teachers' accounts demonstrate that their approach to STEM teaching and learning is underpinned by a *relational intent*, with a clear focus on relationship building and the development of student leadership skills, rather than the desire to demonstrate the level of their scientific expertise; their strengths embody *doing with*, rather than *doing to* their learners. Jane's earlier reflections, on the other hand, reveal that the move to measure the quality of teaching and learning provision and student satisfaction rates in English universities presents challenges for lecturers, particularly regarding perceived shifts in power and control. Jane's comments about some of her colleagues are reiterated by Alex, who conveys the difficulties in changing approaches to teaching and learning from *doing to*, to *doing with*, when traditionally academics have been judged on their research output and subject expertise, rather than their ability to engage and motivate their students:

> There are innovators who do well, then there are colleagues who have been teaching in a traditional manner and it is absolutely appropriate and the students like it…when I say traditional, traditional would be two hours lecture a week and a tutorial every other week and the lectures are in lecture theatre and they have slides and the notes. The slides are on the board and they go through it, the students have hand-outs and they annotate their hand-outs - and that is it. They have question sheets to do and they do them in their tutorials. That I would say is a traditional format, which is absolutely appropriate in certain instances…I think there are colleagues that are committed and passionate that want to do well. And there are colleagues who don't and the problem can be performance management of people who are not up to the required standard. Not because they are not trying, but because they do not want to or they don't have to.

Alex, lecturer in mechanical engineering

Alex's comments illustrate the need to acknowledge the limitations of cross-sector professional learning communities if senior university leaders fail to recognise and advocate the benefits of CPD that support a shift towards universities and academics viewing innovative teaching and learning as *doing with*, rather than *doing to*, their students.

A further point of interest that arose from the data was that, mirroring the findings above, the professional development needs of school teachers could be aligned with the professional strengths of their academic colleagues. Andrea, a primary school teacher, wanted to know more about the ways in which children would be expected to work scientifically *beyond* primary school, and the type of future employment opportunities that STEM subjects can offer her students:

> I want to know where they need to go in particular the working scientifically aspect of it. Knowing what they need to be able to develop further when they get to secondary school. I think that's what I particularly need to develop when I'm teaching…I don't think children realise that there are so many aspects of STEM and so many different jobs you could do based on just the interest in one particular thing. So knowing what it is they are going to do and what sort of things they can do there.

Andrea, primary school teacher

Similarly, Heather would like to develop science teaching and learning that has greater links to what Heather terms the 'real world'beyond the four walls of the school:

> I would like to link more what I do, hopefully speaking to people at the university, to what's actually happening. So making it more real, real science that is taking place … give it more of a context, rather than 'we are going to do this because it is on the exams'… look at new ideas and see how maybe I could use those in my teaching, and then how I could make it relevant to the real world. That is something I hope to find out by making links with the university so, putting science more in a bit of context for the students.

Heather, secondary school science teacher

David's reflections below illuminate the ways in which academics' professional assets can be matched with the professional development needs outlined by his school sector colleagues, Andrea and Heather. His explanations show how, as an academic, his expertise in the practical application of software engineering, and his links with industry, could provide Andrea and Heather with exactly the sort of professional development that they are looking for. David is able to answer Andrea and Heather's queries about how STEM learning is applied in the 'real world' of industry and employment and what the employers want and expect from graduates:

> I run the industrial experience programme, so I deal with students with who are looking to find jobs. … In the first and second year there is a software engineering course that is specifically designed to prepare people for what they might be doing on their placement year, so the two are related…The key thing at university is partnership with industry and employers basically…we can tell students what the employers want…they will listen to employers much more.

David, lecturer in Computer Science

It can be seen therefore, that phase 1 of the project highlighted the ways in which cross-sector CPD has the potential to impact positively on university academic's pedagogic practice in Science, Technology, Engineering and Mathematics (STEM), whilst also offering school teachers the possibility of to developing their scientific knowledge and professional confidence in teaching STEM subjects. The findings point to the benefits of more relational, cross-sector approaches to professional learning in education where participants are able to see and interact with the 'imagined other' from a different sector.

Acting Relationally Supports the Development of Learning Ecosystems in STEM Education

The study found that the immersion event in phase 2 of the study fostered a new form of dialogue between teachers and academics, where academics' preconceptions of teaching and learning in the primary and secondary school sectors started to shift. The reflections of the university academics in this section illustrate their surprise at the level of scientific knowledge and skills in evidence amongst the primary school children (aged 4–11). Furthermore,

participants had not expected such young children to be comfortable using technologically advanced equipment, whilst also being able to critically reflect on *how* and *why* such equipment was being used:

> I sat with a lad [boy] who has told me how a 3D printer works, at a level of detail and so articulate, that if he hit us [enrolled at the university] next week we'd be struggling I think in terms of the facilities we've got and how he'd perceive us…it comes back to… how do you keep that creativity, wrap it in good engineering principles and then push them out into the world of engineering? I still don't think we're there yet – well, it's made me think we're further away than I thought we were.
>
> *Paul, lecturer in Electronic and Electrical Engineering*

When asked for her initial reflections from the immersion event, Eleanor, the university outreach coordinator responded:

> The children clearly had a lot of freedom to look at a topic in a way that interested them. A class of 7-year-olds were designing their own alien species in AutoCAD and 3d printing them, and one boy talked to us in-depth about how 3d printing works and how it might be used in medicine in the future, at a level well beyond what I would have expected from someone his age.
>
> *Eleanor, university outreach coordinator*

It was notable that the university participants were so surprised by what they were observing in schools. This was not only surprise at the variety of approaches to teaching and learning that were being used, but also at the ways in which teachers were encouraging young children to be independent learners and critically reflective thinkers. This led Jackie (university outreach manager) and Jane to start to link these findings to question their current approaches to STEM teaching and learning practice in higher education. Jackie wondered how reflective practice could be better applied in university classes:

> Greater reflective practice is required – how can I utilise "active reflection" in classes that I teach and how can we teach students to use active reflection? How can we enable students to be more flexible in the learning approaches they use to solve problems? Can active reflection be one of these learning tools?
>
> *Jackie, university outreach manager*

Following her observation of a primary science class, Jane considers how the primary school teacher had approached assessment for learning in her classroom and had developed an environment in which the children were asked questions by their teacher - and were confident when answering, suggesting that the immersion event is producing a shift in Jane's thinking:

> You obviously got them to accept, or to have that expectation that *you* would ask questions. When they were talking amongst themselves and they were asking questions, you would, for example, pick someone to answer a question. I find that really interesting because that's one of the *massive* challenges in lecturing, or in a big group of students, they *never* want to answer.

Jane, lecturer in chemistry

Jane's previous assumption had been that her university students do not want to answer questions, so the fact that very young primary school children "have that expectation" that their teacher will ask them questions, and that the children were happy to answer, was an unexpected finding for Jane. As she talks to her primary sector colleague, Jane starts to informally identify the underpinning pedagogical approach that has facilitated the children's willingness to answer questions, referring indirectly to student-centred approaches to teaching and learning such as the teacher getting the children to 'talk amongst themselves' and then 'picking someone to answer a question'.

As a result of being able to observe the reality of the practice of the 'imagined other' (the school teachers) during the immersion event, Jane and her academic colleagues began to consider how young people's school learning experiences impact on their expectations as they transition from school to enrol in STEM courses at university. It is evident that, as a direct result of their engagement in the immersion event, the academics had started to reassess their understandings of STEM teaching and learning in schools, and were better able to see the value of school-university professional development partnerships in helping to engage and motivate STEM learners in the HE sector:

> I suddenly realised; give these kids a few years on us, they're going to come to the university. Are we going to be ready for the learning styles, are we going to be able to meet their expectations?
>
> *Paul, lecturer in electronic and electrical engineering*
>
> It was very interesting to see the perspective on engineering from potential future students at a much younger stage than the applicants that I normally interact with in Year 12 and Year 13 (University Open Days and UCAS Visit Days). It's made me think twice about how we make sure that we are not complacent when we are trying to attract these young people to our university.
>
> *Karl, senior lecturer in electrical and electronic engineering*
>
> The visit to the vocational academy school made me realise that the university will have increasing competition from degree apprenticeships for the best students and needs to position itself accordingly…It will certainly change how I talk to students about their careers and the value of what they have done at university.
>
> *David, lecturer in computer science*

As the university's outreach manager, Jackie usually approached her work by considering how the expertise of STEM academics can be taken into schools. However, a particularly interesting aspect of this research was how this study's cross-sector, *relational* approach to professional development, and its deliberate intent to build relationships, develop leadership and bridge gaps in culture and power, had started to shift Jackie's notion of 'outreach' work:

> the visit was informative and thought-provoking. It was a valuable opportunity to see at first-hand how teachers at both primary and secondary level are delivering some of the curriculum topics that we ideally would like to link to in our outreach work. Usually I

> am looking for examples of high-level university research topics that lend themselves to being summarised, broadened out and connected, in a rather 'top down' way, to the experience of learners who have only basic knowledge of the essential concepts. So it was really interesting to see from 'bottom-up' the sort of level at which some of our key audiences might be able to relate to what our academics and researchers are working on...it made me think about what assumptions we make about what school education is in the 21st century and how important it is to make a lot of effort to explain what goes on at a university so that young people believe they can access this if they wish.
>
> *Jackie, university outreach manager*

The extract above illustrates how, through her engagement in the immersion day event, Jackie is starting to see that the university could adopt an *asset based* approach to its outreach work with schools, as opposed to starting from a "a hierarchical approach in which the university dominates and practitioner knowledge is devalued" (Greany et al. 2014 p.6). Jackie begins to consider how the university could instead focus on the skills, knowledge and abilities that *are already evident* in STEM school classrooms, or as Jackie terms it, redefine outreach work from the "bottom-up". The change in Jackie's thinking is reiterated by her comment after the immersion event:

> You just sort of forget how good they [primary school age children] are at things and I think expectations have to be higher, I think we underestimate what they can do.

Participants also began to articulate ways in which cross-sector professional learning partnerships could enable academics and teachers to negotiate their different knowledge bases in order to improve STEM teaching and learning across *all three* sectors of education (Nelson 2005), changes in thinking that had occurred as a direct result of the immersion event and the professional learning relationships brokered by SEERIH:

> In the future I would be very keen to show to primary and secondary school teachers what electrical and electronic engineering is about! Maybe in cooperation with other engineering schools we could put on a half day workshop that highlights how we teach future engineers. I would also like to reinforce the idea to them just how important mathematics is…within our curriculum and that whilst tinkering is a very good way to get young people interested in engineering it is the engineering science and quite sophisticated mathematical models that have taken humans to the moon and back.
>
> *Karl, senior lecturer in electrical and electronic engineering*

Conclusion

The current English education landscape is characterised by several major issues for policy makers and practitioners, including the need to improve STEM teaching and learning and an increasing acknowledgement that our education systems need to adapt and change in order to respond to rapid global shifts in economic and technological development. This study adds to the body of evidence that advocates the need to develop these initiatives, by pointing to the ways in which the brokerage of professional learning relationships can support the

development of *both* these initiatives in tandem. Although it is necessary to acknowledge the limitations of the project, it reveals how the brokerage of university-school partnerships can influence university academics' pedagogic practice in Science, Technology, Engineering and Mathematics (STEM) and indicates the value of adopting a relational, cross sector approach to CPD, yielding three key areas of interest for further research:

Firstly, following Warren et al. (2009), this research places an explicit emphasis on two key areas: relationship building amongst and between different stakeholder groups and efforts to bridge the gap in culture and power between university academics and school teachers. Using a relational lens to frame the project reveals shifts in understandings of professional and relational identities. The academics have started to think differently about their current pedagogical practices and to identify themselves as professional 'learners' in STEM education, as well as experts in their field. This study points to the potential of a relational approach to STEM CPD to create spaces of possibility for cross-sector dialogue that can help participants to begin to question their previously "self-interested conceptions of professionalism". Instead, through relationship building with the *imagined other*, school teachers and academics have the opportunity to move towards more activist and inclusive forms of professionalism, which can "provide systematic ways of thinking and acting in the best of interests of all those who are involved in education"(Sachs 2000, p.79).

Secondly, subverting the traditional power dynamics in school-university partnerships helps to encourage the development of professional learning as a relational, outward looking endeavour. The project deliberately adopted an asset-based approach to school STEM provision, rather than using a model based on school deficits. The starting point for this was the explicit acknowledgement and valuing of the skills and knowledge (assets) that schools and teachers can offer to university academics to support the improvement of teaching and learning in the HE sector. Providing the opportunity for academics to go into schools as *learners*, rather than *experts*, generated a different type of professional knowledge exchange about teaching and learning, focusing not only on "professional learning" but also "capacity creation"(OECD 2015, p.20) through cross-sector knowledge exchange.

Finally, relationships between university academics and school teachers were brokered and developed by the Science Engineering Education and innovation Hub (SEERIH) at The University of Manchester. SEERIH's role was pivotal in changing professional and relational identities and in developing STEM education as a relational, outward looking endeavour. Through its use of research-informed practice, SEERIH was able to act as a "change agent", to "exercise influence on the ground and provide the expertise and drive to sustain the innovation" (OECD 2015, p.20). The brokering of relationships and the design of cross-sector professional learning opportunities enabled a more communal way of working that facilitated new forms of reciprocity between teachers and academics, resulting in STEM educators from different education sectors being better able to "understand the nature and limitations of each other's work and perspectives (Sachs 2000, p79). This way of working increased the potential for STEM education to move from a landscape of distinctly different and clearly boundaried education institutions towards the creation of more flexible cross-sector ecosystems of teaching and learning.

As a result of the conclusions from this study, a second cross-sector CPD project has been developed. University academics, postgraduate students and school teachers are currently working in cross-sector teams to collaboratively research and plan Science and Engineering lessons in both university and school settings, lessons that set out to improve teaching and learning by addressing the areas for professional development identified in this study. This second project addresses the major lesson learnt from this study, namely the need to provide

opportunities for 'just-in-time' learning (Novak et al. 1999). Participants in the second project are using the key areas for development identified here to inform the collaborative planning and delivery of STEM sessions. For the university academics these areas are: assessment for learning and the development of student-centred and collaborative teaching and learning strategies. By running the project in this way, research articles with ideas for specific areas of STEM teaching and learning practice can be signposted for teachers and academics as and when they are needed, rather than offering resources *just-in-case* - "on the premise that a teacher may use the technique at some future point" (Bates 2000; Gallant 2000; Feist 2003; Harwood and Clarke 2006 p.32).

The findings from this paper illuminate the implications for future research in the area of cross-sector CPD in STEM education. It reveals how, by adopting a relational, asset-based approach to university-partnerships, research can help to change practice, repositioning the imperative of constant change in education reform as a relational, outward looking endeavour that can help to support thriving ecosystems of professional development in STEM education.

Funding This project is internally funded by the CHERIL unit (Centre for Higher Education, Innovation and Learning) at The University of Manchester.

Appendix

Phase 1: semi-structured interview questions

1. Can you briefly describe your role and experience in the teaching STEM or Science?
2. What are the strengths or expertise you have in teaching STEM or Science?
3. What are the areas of your teaching that you wish to develop/change?
4. Would you say you align with a particular framework, philosophy or theory when you teach?
5. What would you say are the things that support you to teach in the way you wish to?
6. What would you say are the things that create challenges or barriers to teaching in the way you wish to?
7. What is your perception of how STEM is being taught at university/in a secondary school/primary school setting? Do you have any previous experience of this setting?
8. What do you expect to take back from being involved in this project?

Phase 2: semi-structured questions for reflection-on-'cross-sector-practice' (post 'immersion' day)

1. What did you want to get out of this visit?
2. What are your initial reflections from the visit?
3. Has anything particularly surprised you or been of key interest?
4. What questions has the visit raised or challenges has it posed for your own teaching and learning practice?
5. To what extent has the visit 'changed' or influenced your thinking about teaching and learning?
6. Has it influenced your thinking about your own teaching and learning practices?
7. What would you like to explore further as a result?

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