

# **Crossing the boundaries: Collaborations between mathematics and science departments in English secondary schools**

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## **Abstract**

There are many calls in the literature for school science and mathematics departments to collaborate. They are largely in response to perceived similarities in content yet few studies explore how such collaborations might work. This paper explores how mathematics and science departments actually work together in schools in England. It is unusual in its focus both on collaborations which arose organically rather than as the result of a specific intervention and in its focus on the views of practising teachers. Six schools were visited and semi-structured interviews carried out with the teachers most closely involved in collaborating to explore their perspectives and insights. The findings show that collaboration is possible and it can be approached in a variety of ways although it is often fragile and difficult to sustain. Collaboration can be a key site of professional learning for teachers, particularly about the ‘other’ curriculum. Informal conversations across departments were highly valued, but tended to be between those with a well-established pre-existing relationship. Contrary to the idea that there are similarities it can be a significant challenge for teachers to find points of overlap between curricula.

Keywords: science, mathematics, collaboration

## **Introduction**

### ***Calls to work together***

There have been a number of calls in the literature and more widely for school science and mathematics departments to work more closely together. Arguments for such closer alignment are often based on perceived synergies in subject content such that there is, it is argued, substantial overlap between the subjects which consequently makes

collaboration useful, not least in saving time (see: Dodd & Bone, 1995; Orton & Roper, 2000; Pang and Good, 2000; Osborne, 2011; Zhang, Orrill, & Campbell, 2015; Boohan, 2016). For instance, Zhang *et al.* argue that ‘*mathematics and science share a coherent set of values and concepts*’ (2015, p. 358) including problem solving and process skills. They suggest that: ‘The content of both science and mathematics should encourage teachers to integrate and use new knowledge and skills from across areas of competence’ (ibid.). Zhang *et al.* also suggest that it should be relatively easy to find overlap in the content of the two curricula.

The other main arguments for closer working include: shared values and skills (Berlin & White, 1995); a resulting improvement in students’ scientific and mathematical understanding (Pang & Good, A Review of the Integration of Science and Mathematics: Implications for Further Research, 2000); an opportunity for teachers to appreciate similarities and differences in the curriculum (Boohan, 2016); that it promotes transfer between the disciplines (Honey, Pearson, & Schweingruber, 2014); and, that it enhances pupil engagement particularly when ‘real world’ contexts are used (Williams *et al.*, 2016, Venville, Wallace, Rennie, & Malone, 2002, Honey *et al.*, 2014).

### ***Limited existing research***

In spite of these calls for collaboration, Osborne rightly identifies a lack of research exploring how science and mathematics educators can actually work together more closely:

Science and mathematics education exist at a distance from each other – the two communities rarely engage and there is an absence of a literature that explores how they could work symbiotically. (2011, p. 98)

Those who have surveyed the literature on mathematics/science collaboration (including Czerniak & Johnson, 2014; Orton & Roper, 2000; Pang & Good, 2000;

Becker & Park, 2011; Honey, Pearson, & Schweingruber, 2014) agree that there are very few empirical studies. Those which do exist have often researched the outcomes or impacts of a specific intervention. For example, Frykholm and Glassom (2005) and Koirala and Bowman (2003) studied their integrated pre-service teacher education programmes; Weinberg and Meeking (2017) followed up an intervention with serving science and mathematics teachers.

This study is, in comparison with previous studies, unusual in its focus on collaborations which have arisen organically in schools rather than resulting from any particular intervention. It asks:

- Why do science and mathematics teachers begin to collaborate?
- What do mathematics-science collaborations look like in practice?
- How do teachers from the different departments communicate with each other?
- What professional learning arises from such collaborations?

Very few of the existing studies have focused on serving teachers' views and practice of collaboration or explored why, aside from being part of an intervention, teachers might choose to begin to work across departmental boundaries. This study addresses that gap.

### ***Terminology***

Searching the literature for previous research about mathematics/science collaboration is made challenging due to wide variation in language and terminology. Many authors call any working together 'integration' but a number of authors, for example, Czerniak, Weber, Sandmann and Ahern, (1999), Berlin and Lee (2005) and Williams *et al.* (2016) argue that the term integration is problematic, largely because there is a lack of an agreed definition. We have chosen the term collaboration, and use it to mean any form

of working together by teachers from mathematics and science disciplinary backgrounds and departments.

### ***Collaboration***

Many authors have written about collaboration (see, for example, Perkins, 2003; Carlile, 2004; Edwards, 2011) but whatever the context they virtually all agree that collaboration across boundaries, including disciplinary boundaries, is not straightforward. Wilson, Schweingruber and Nielsen (2015), however, argue that collaboration can be a key site of teachers' professional learning and development. However, they note that evidence of a resulting 'learning environment for teachers of science is both limited and diffuse' (p.148) and that where there is a focus on collaborative practices it is a departure from the more individualistic cultures which characterise most school workplaces. Wilson *et al.* (ibid.) further note that relatively few studies have explored how teacher interaction supports teacher learning, particularly in science education. Finally, Wilson *et al.* (2015) found that workplaces are often poorly organised to support collaboration thus building and sustaining it can be a key challenge, with access to external support frequently a factor in maintaining it.

Collaborative practice is more likely to be found within departments than across departments. For example, science departments frequently have a team-room which is generally only used by members of that department. This team-room can be a caring and supportive place and is a key site of collaborative learning (Burn, Childs, & McNicholl, 2007), but when science staff spend the majority of their time within the department they do not get to know members of other departments, including the mathematics department.

In terms of research into the nature of collaborations, Nelson and Slavit (2007), in a study of mathematics-science teacher professional learning community groups, found that teachers appreciated the opportunity to familiarise themselves with the ‘other’ curriculum. Nevertheless, the teachers found it challenging to find common ground across mathematics and science for an inquiry project, with many struggling ‘*to define an inquiry question that would cut across the disciplines*’ (p. 29). As a result, they tended to focus on ‘*pedagogy or classroom processes as opposed to specific disciplinary ideas and student understanding*’ (ibid.).

### ***Theoretical framework: boundaries and exchange value***

#### ***Bernstein and boundaries***

There are boundaries around mathematics and science departments in schools, and mathematics and science teachers working together must cross them. Bernstein’s ideas of classification (2000) can help to explain why boundary crossing is a major challenge.

Bernstein argues that in order for categories (in this case school subjects) to be different from each other, they need a space in which to develop their unique identity. This space exists in the distance which separates one subject from another. As Bernstein puts it, in order to be differently specialised ‘they must have a space in which to develop their unique identity [...] and special voice’ (p. 6). He argues that the crucial space which allows the specialisation:

is not internal to that discourse but it is the space between that discourse and another. In other words, A can only be A if it can effectively insulate itself from B. In this sense, there is no A if there is no relationship between A and something else. The meaning of A is only understandable in relation to other categories in the set [...]

If that insulation is broken, then a category is in danger of losing its identity, because what it is, is the space between it and another category. Whatever

maintains the strengths of the insulation, maintains the relations between the categories and their distinct voices. (Bernstein, 2000, p. 6)

In other words, the identity of one subject is reliant on it being different from, separated from, or insulated from another subject. Thus science can only be science if it can effectively insulate itself from mathematics; mathematics can only be mathematics if it can effectively insulate itself from science. If the insulation between the categories is broken then it can become impossible to identify where one ends and the other begins and their unique identity is eroded.

In cases where classification is strong, the boundaries between subjects are strong and the subject is well insulated. The insulation between mathematics and science in school is produced by differences in discourse and language, by specialised teachers, by specialised teaching spaces and support staff. In English secondary schools, the boundaries between the sciences – biology, chemistry and physics – are reasonably strong; the boundary between science and mathematics even more so.

School departments are usually led by a head of department (often referred to as a Chair in North America) and Bernstein (2000) suggests that in a strongly classified system, it is the heads of department who will communicate rather than other members of the team. Ball (1987) noted that relationships between departments are frequently characterised by conflict:

Conflicts over access to scarce resources – time, personnel, capitation, territory and pupils, or at least particular varieties of pupils – are enjoined between departments. (Ball, 1987, p. 42)

Ball argues that ‘where relationships between teachers are poor almost any attempt at innovation can be seen [by colleagues] in terms of the political motivations or career aspirations of the instigators’ (1987, p. 227). Thus, unless the relationship

between the departments is good in the first place, science or mathematics teachers trying to collaborate might very well be viewed with suspicion.

Bernstein argues that '*attempts to change degrees of insulation reveal the power relations on which the classification is based and which it reproduces*' (2000, p.7).

Educational change can arise in a variety of ways but Ball (1987) identifies the headteacher as critical. It is the head who usually introduces change into the school and even when this is not the case their support is necessary for any innovation proposed by another member of staff (Ball, 1987). The head can also be critical in resisting change. The key role that the headteacher and senior leadership team play was also identified by Straw, MacLeod and Hart (2012) who found that change in practices within and between departments proved difficult in schools where that innovation did not feature among senior leaders' priorities or have their support.

Were a teacher to wish to work collaboratively across science and mathematics, they would need to have their head of department onside, as well as the headteacher and the head of the other department. In a busy school, getting this much agreement between parties could prove a significant barrier.

### *Obstacles and exchange value*

In a review of interdisciplinary mathematics education, albeit not focused specifically on links with science, Williams *et al.* note that:

Interdisciplinary work can be difficult, confronting certain sorts of obstacles, power structures, and questions of identity, differences in understandings of knowledge, discourse and practice. (2016, p. 6)

Given all these obstacles and barriers, the surprise is not that interdisciplinary work or integration is rarely found, but that it is found at all. Williams *et al.* argue that as a person becomes more associated with a discipline and identifies with it, they can



become blind to other disciplines, or see other disciplines in a distorted way, creating further challenges to working in an interdisciplinary manner. In particular, they identify a problem with interdisciplinary projects. In the normal organisation of society, products are exchanged by means of what they call a 'generalised exchange form' (p. 10); in most instances this process takes the form of money. Participants in the exchange know what they are giving and what they are receiving. Williams *et al.* argue that when two or more disciplines work together they may have no medium of exchange. They argue that it is hard to define a common objective which often leads to the failure of interdisciplinary projects. In successful projects the outcomes makes sense within each discipline. Thus considering the outcomes of a joint enterprise, and how those outcomes contribute to broader educational outcomes in each of the disciplines, is arguably a key to successful interdisciplinary work.

What drives this study is that, in our professional experience, examples of science and mathematics collaborations can be found. The existence of these tantalisingly rare examples of success provide opportunities to investigate questions such as: Why do science and mathematics teachers begin to collaborate?; What do mathematics-science collaborations look like in practice?; How do teachers from the different departments communicate with each other?; and, What professional learning arises from such collaborations?

### **The study**

The most challenging aspect of this study was to identify suitable schools to participate as collaboration between mathematics and science departments is unusual. The study necessarily required purposive sampling with schools invited to participate that possessed required characteristics (Cohen, Manion, & Morrison, 2011). Research visits were paid to six English secondary schools (five state, one fee-paying) known for some

aspect of mathematics/science collaboration in 2014-2015. At each school, semi-structured interviews were carried out with those teachers most closely involved in the collaboration; in total there were 15 interviews each about an hour long. In addition, observation data about the organisation of the departments and the location of the teaching spaces were collected and, where appropriate, documentary data including policies and curriculum booklets related to the collaborations. For further details about how schools were chosen for the study see Wong (2018).

Whilst the original intention was to interview the head of science, head of mathematics and a member of the senior leadership team it became apparent that these were often not the people most closely involved in the collaboration and in only one school were people who held these three posts interviewed. In two schools a key person involved in the collaboration had left and in these schools there was only one participant. While we would have preferred multiple perspectives to each collaboration, these two schools provided important insights, particularly into how and why collaboration can reduce or even cease and thus are included even though they did not quite fit the original research design. Unlike in some other countries, senior leaders in schools in England almost always teach themselves, (as did all those interviewed) alongside their leadership responsibilities.

### *Ethics*

BERA ethical guidelines (BERA, 2011) were followed and the planned study approved by King's College London research ethics committee. A particular ethical consideration is that of conversations which could have the potential to cause dissent within the school. There are different degrees of anonymity (Wengraf, 2001) and we anticipated that participating teachers will be able to recognise themselves and therefore their

colleagues in what is written and thus we have taken great care in how we have reported, for example, descriptions of friction or frustration between colleagues and school departments. Such relationships can be fragile, as this study shows, and we would not wish participation to lead to further tension.

### ***Interviews***

All of the interviews were carried out by the first author – an interview schedule is available in appendix 1. Questions focused on the nature of the collaboration, how and why it began and challenges teachers faced in building and maintaining it. The researcher's background as a teacher helped in developing trust giving her greater access into teachers' worlds and giving her the 'empathy to elicit personal stories [and] in-depth description' Rubin and Rubin (1995, p.13).

The interviews were transcribed (intelligent verbatim) and data analysed using NVIVO to manage the data. Data were coded using a complete coding process as recommended by Braun and Clarke (2013), with inductive coding based on the data set (Charmaz, 2006). Most codes were evident in more than one interview and some were present in most interviews (Braun & Clarke, 2013). All coding was carried out by the first author in discussion with the second author and other colleagues. Themes were developed from the codes as described by Braun and Clarke (2013). Findings from the interviews were checked against each other and discussed by the authors. Different styles of collaboration were compared and grouped according to type, as were the modes of communication between departments.

All names including school names are pseudonyms. The schools interviewee codes are as follows: the first letter corresponds to the school (A-F), the second to the subject (S - science, M - mathematics, T - technology) and there is an L added for a senior leader.

## The schools

In this section we describe the schools, the participants and the nature of the collaboration. Details of the schools, the departments and the participants are shown in Table 1.

School	Description	Departments	Participants
A	Large, mixed, semi-rural 11-18 comprehensive school with a low proportion of pupils eligible for free school meals. Part of a small, local, academy chain with day-to-day running overseen by deputy headteachers. Teachers meet those from other departments in the main staffroom.  5 X 1 hour lessons per day	Science and mathematics departments separate, each with a Head of Department.	‘ <b>AM</b> ’, AST (Advanced Skills Teacher) mathematics  ‘ <b>AS</b> ’, head of physics  ‘ <b>ATL</b> ’, deputy head, engineer and teacher of design technology (who has also taught both mathematics and science)
B	Large, mixed, urban 11-18 comprehensive school with a high proportion of pupils eligible for free school meals. Part of a national chain of academies, the	Faculty of mathematics, science and technology (MST).  Small faculty staff workroom. Some	‘ <b>BSL</b> ’, principal, biology teacher  ‘ <b>BS</b> ’, vice principal, head of MST and chemistry teacher

	<p>principal oversees this school only. Follow the ‘Opening Minds’ curriculum in year 7 and 8 which is based on competencies rather than subject content (RSA, 2017).</p> <p>Brand new building designed to allow for collaborative and integrated teaching. No staffroom – staff use the student restaurant for conversations.</p> <p>3 x 2 hour lessons per day</p>	<p>fully equipped science laboratories, but most MST teaching rooms are carpeted and have only a single sink and no gas taps. They are in groups of four with flexible walls which can be opened up to form a large space to accommodate the equivalent of two or four classes (60 or 120 students).</p>	<p>‘<b>BT</b>’, head of Year 7 and 8 MST who oversees the integrated curriculum, technology teacher</p> <p>‘<b>BM</b>’, head of Year 7 and 8 mathematics</p>
C	<p>Fairly small urban 11-18 state school with a large proportion of pupils eligible for free school meals.</p> <p>New building designed to promote collaboration between the groups of</p>	<p>Science and mathematics are in a faculty (the ‘practical zone’) together with PE and Design Technology. Science and mathematics teaching rooms have</p>	<p>‘<b>CML</b>’, assistant principal and head of the practical zone, mathematics teacher</p>

	<p>subjects in each zone. No central staffroom.</p> <p>6 x 50 minute lessons per day</p>	<p>glass walls looking onto the corridor.</p> <p>Zone staffroom.</p>	
D	<p>Relatively large, mixed, 11-18 school in a small town, with a low proportion of pupils eligible for free school meals, falling roll due to the demographics of the town. Central staffroom.</p> <p>5 x 1 hour lessons</p>	<p>Science and mathematics departments separate, each with a Head of Department. Science team room.</p>	<p><b>‘DS’</b>, head of science</p>
E	<p>Small 3-16 girls’ independent (fee-paying) day school. Central staffroom.</p> <p>5 x 1 hour lessons</p>	<p>Science and mathematics are in a faculty together, led by the head of science. Mathematics moved to be physically adjacent to science some years earlier. Faculty team room.</p>	<p><b>‘ESL’</b>, head, physics teacher</p> <p><b>‘ES’</b>, head of science and mathematics faculty</p> <p><b>‘EM’</b>, head of mathematics</p>

F	Large, mixed, 11-18 urban school with a high proportion of pupils eligible for free school meals  5 x 1 hour lessons	Science and mathematics departments separate, each with a Head of Department, although near each other on the large site. Science team room.	<b>'FML'</b> , vice-principal, former head of mathematics <b>'FM'</b> , mathematics teacher, overseeing 'mathematics across the curriculum', physics degree <b>'FS'</b> , head of science, physics teacher
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*Table 1: The Schools, departments and participants.*

### **The collaborations**

In this section we will explore what the mathematics/science collaborations looked like in practice. Seven different types of collaboration or ways of working together (Table 2) were identified in the data; each is discussed in turn.

<b>Type of collaboration</b>	<b>Schools</b>
a) Joint projects	A, C, D
b) Integrated teaching (including longer projects)	B
c) Visiting expert	A, C
d) Informal conversations	Particularly E, but all except D
e) School visits	C, D, E
f) In the curriculum and scheme of work	B, E, F

g) Combined year 11 and 12 mathematics and physics lesson	A
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*Table 2: Types of collaboration in the schools*

***a) Joint projects***

Projects which were run across mathematics and science – and in some cases technology – were what many people described when asked about mathematics/science collaboration. These projects were in different contexts and were organised in different ways, but all were for key stage 3 (age 11-13) pupils.

*School A*

School A had twice run a week-long joint project for Year 9 based around whether a bath would cool more slowly with bubbles. They were not very pleased with this as a context, but had struggled to find one more suitable; similar to difficulties highlighted by Nelson and Slavit (2007). Work was divided clearly between what had to be done in science and in mathematics in successive lessons. AM and AS wanted to include both the data handling cycle for mathematics and investigations for science, and to produce data which could be used with both a mathematics and science focus. AM was keen to ensure students understood both the similarities but also the differences in how mathematics and science would use the information. AM and AS described many of the problems encountered as logistical. Students were not in the same classes for mathematics and for science and so would arrive in lessons having got to different places in the work, making life very difficult for the teachers and for AM and AS as coordinators, ultimately leading to the projects' demise.



### *School C*

At School C, the joint project was between mathematics, science, technology and physical education, and lasted half a term (about 6 weeks) at the start of Year 7. The project was about making smoothies (a blended fruit drink), although CML hoped to find a more rigorous context for a future project, and included statistics in mathematics and digestion and energy in science. The original idea was that teachers from different disciplines would team-teach, but in the end it was decided that it would be easier to deliver if the content was split between the different subjects, thus side-stepping the issue of different grouping found challenging at School A. Teachers were reported as being happy with the project and it was expected to be run in future years.

### *School D*

School D had had two separate projects. A simpler one for Year 7 involved Hooke's Law with students doing some practical work in science before taking the results to use in mathematics. This initiative had been dropped some years earlier, but was described by DS as a mathematics project that science assisted. The Year 8 project was in the context of the topic 'Space' and involved several lessons across both mathematics and science, together with a trip to the National Space Centre. The project began with the science context to which the mathematics was added; identified by Pang and Good (2000) and Frykholm and Glassom (2005) as a common approach in joint projects. Students had a booklet and were expected to work largely independently to research and complete the work which could be done in either mathematics or science.

As the sets were different in each subject they had tried rearranging classes for the duration of the project, but this had not been successful and caused difficulties with classroom management; previously recognised by Czerniak and Johnson (2014) as a barrier to integrated teaching. In a subsequent year students were left in their usual

classes, but this constrained their choice in terms of project partners. Not all students responded well to the increase in responsibility they were given for managing their own learning, and the difficulties this caused had never been resolved. The integrated project thus did not enhance pupils' engagement with science and mathematics, although this was suggested as a key goal for integration by Venville *et al.* (2002) and others.

### ***b) Integrated teaching***

#### *School B*

The integrated teaching at School B consisted of joint projects, originally for all of the mathematics, science and technology teaching in Years 7 and 8. The projects were jointly planned by a teacher from each of mathematics, science and technology who decided the subject content and the competencies from the 'Opening Minds' curriculum which was taught through that unit. The teachers acknowledged that initially subject content was sometimes lost in the focus on competencies, with healthy eating studied several times, and this was demotivating for students and frustrating for the teachers. All the School B participants agreed that teaching integrated MST is difficult for many reasons, including that it challenges secondary teachers' identities as subject specialist teachers as well as requiring them to teach material that they may well not be familiar with – both factors identified by Venville *et al.* (2002) as barriers to integrated teaching. The principal had decided that the following year students were going to spend more time in separate, rather than integrated, subjects due to concerns about student progress.

### ***c) Visiting Expert***

The 'Visiting Expert' model for collaboration had been developed by AM and AS at School A. They spoke about it at a national education conference and, as a result, School C tried the idea, with some apparently small but significant alterations.

### *School A*

For AM and AS, 'Visiting Expert' was a quick and simple way to collaborate. It involved one teacher going into the other's lesson to do a 5-10 minute introduction to an aspect of mathematics which would be useful in science or vice-versa. They gave two examples of its use: AS had talked about mirrors and reflection and set up a problem for AM's lesson about symmetry. AM had talked about calculating the volume of complex shapes by approximating to a straightforward shape as an introduction to AS's lesson on lung capacity. Although they had not used 'Visiting Expert' extensively, both felt that even occasional use was beneficial, and in each case there had been some prior planning. Indeed, finding examples could be challenging and both recalled that when AM originally asked for contexts for teaching symmetry AS struggled to think of any, eventually deciding on angles of incidence and reflection. These are not often described as 'symmetry' in school science, although clearly they are an example of it. These difficulties are an example of the difference in discourse identified by Williams *et al.* (2016) as a barrier to collaboration.

### *School C*

At School C, the close proximity of departments and the glass walls of the classrooms allowed staff to pull in passing teachers to use them as visiting experts. They found, however, that many staff found being put on the spot like this stressful in case they were shown up as lacking knowledge in front of the class. This is significantly different to the way the visiting expert approach was carried out at School A, where AS was happy to admit that it had taken several minutes' discussion and thought to answer some of the questions posed by AM. There is a real difference in having these discussions in the staffroom compared to having them in front of a class.

#### ***d) Informal conversations***

In five of the six of the schools informal conversations (that is, not part of timetabled meetings) about the curriculum happened between members of the science and mathematics staff. Most participants also noted that this was not common practice in other schools they had worked in. Three of the schools (B, C and E) had deliberately placed the science and mathematics departments in close proximity, with common work space to encourage such conversations. In School F, the departments were near each other but did not have any space in common. School A and School D were more typical secondary schools with departments not particularly near to each other and one staffroom for all staff.

It was at School E where the informal conversations were really the heart of the collaboration with science and mathematics staff meeting informally at break times. ES and EM clearly felt that it was in the talking and the conversation that they resolved the majority of any difficulties, effectively breaking down the differences in discourse identified by Williams *et al.* (2016). Both they and the school head suggested that this type of collaboration was easier and more likely in a small school; it was also evident that it did take a considerable amount of time, with such conversations occurring in most break and lunchtimes.

#### ***e) School visits***

School C had taken all of Year 8 to the London Natural History Museum and had given them a trail round the museum which included some science-based and some mathematics-based questions. Schools D and E had taken joint trips to the National Space Centre accompanied by both mathematics and science teachers and School E were planning an environment day out to include calculating heights of trees using triangles and quadrat work with simple statistics.

***f) Collaboration in the curriculum and scheme of work***

We are taking curriculum collaboration here to mean more broadly across the curriculum than in a one-off short project. School B again takes curriculum collaboration further with two years of integrated teaching, as discussed above.

*School E*

At School E, EM and ES have produced a policy which sets out how language will be used across the two subjects. Points include that mathematics staff would continue to point out the different types of averages; science staff would make clear that while there were different averages, the one used in science was the mean. They have agreed lists of names for equipment, such as protractor not angle measurer, and have agreed a common policy as to how graphs are to be laid out. Both EM and ES felt that having this policy allowed them to save time in an overcrowded curriculum. The policy helps to further break down the differences in discourse, knowledge and practice identified by Williams *et al.* (2016). It does, however, reduce the freedom which individual teachers have in the way that they teach. An example was given of a science teacher who taught students to do graphs in a way that was not in accordance with the policy, although it would be deemed correct in external science examinations, and how he had to be brought into line. It would be much harder to do this in a large school where there could easily be at least 12 teachers of each subject, often physically spread much further apart, than at School E with four science and two mathematics teachers.

At School E they have also looked at the skills required of their pupils in each year to ensure that if science requires mathematical skills that have not yet been taught in mathematics, science teachers are at least aware of it and know that they will have to teach those skills. The mathematics department will move their curriculum to aid science if they can, but they will not do so at the expense of what they feel is the best

order for their curriculum. This is the type of collaboration encouraged by Boohan (2016).

#### *School F*

Understanding of what is taught when by each subject is also evident at School F. FS was well aware that there are mathematical skills required in science which not all students will have mastered, and planned time in the science curriculum for coverage of mathematics skills where necessary.

#### ***g) Combined year 11 and 12 physics and mathematics lesson***

School A organised a lesson aimed to give the students a look at some science and mathematics which was beyond the curriculum. The lesson was based on the press release from CERN when they thought they had data to show particles were travelling faster than light, but did not actually believe their own results (CERN, 2011). Students were shown a documentary about the dilemma followed by some input on a particular equation (the Lorentz transformation). Students worked in groups through some qualitative and quantitative examples of similar problems. It was a very popular session, although a huge amount of work to set up. They would like to do something similar again, but would not be able to use the same context in the following year as many of the same students could potentially be involved.

#### **Modes of communication**

We turn next to the question of how staff from different departments communicate with each other. From the data, five modes of communication could be determined.

### *i) Lesson observations*

The lesson observations discussed were nearly all part of the schools' reporting and management structures and undertaken by more senior teachers. Those who had observed or been observed by a teacher from the 'other' department described it as useful in learning about the similarities and differences between the subjects.

### *ii) Joint meetings*

All joint meetings reported were for planning a joint project rather than talking about mathematics and science more generally, although at School F they planned to invite the head of mathematics and perhaps another mathematics teacher into a science meeting to talk about the mathematics curriculum.

### *iii) Informal conversations*

Informal conversations took place between individual teachers or small groups from different departments. They were not in scheduled slots and often came out of a pre-existing friendship. Informal conversations took place between individual teachers or small groups from different departments. Such conversations were not in scheduled slots and often came out of a pre-existing relationship. For example:

One of my very good friends is the head of key stage 4 in science and we talk quite a bit about this [mathematics-science]. [FM]

Having got to know each other [...] we then started having conversations. [AM]

The participants who engaged in these types of conversations often had a broader awareness of the differences between mathematics and science. Many teachers pointed to these kinds of conversations as being the most useful in producing their knowledge of the differences. For example:

Working with teachers from another department can be quite eye-opening as well, as to how they work, how they plan, ideas they have. Even that short 2 or 3 minute discussion [...] can be quite fruitful. AS

I would argue that it is the absence of power in these relationships which allows understanding to flourish in informal conversations. The absence of power reduces the boundaries which are, according to Bernstein (2000), created by power relations.

*iv) Students as a source of information*

Some of the teachers cited students as a source of information about what they learn and how in other subjects, although other teachers suggested that students are not always the most reliable guide to their prior learning. The need to trust in sometimes unreliable information from students demonstrates the frequent lack of communication between the departments.

*v) Key personnel*

In four of the schools there was a key person who facilitated the communication between departments. In School A, AM; School C, head of STEM (who had left); School D the deputy head (now left); and, in School F, FM in charge of mathematics across the curriculum. That this key person was essential for not only building but maintaining the lines of communication was seen in School C and School D where both those key people had left. Those interviewed in each (and it was only one person in each school) noted that the departure of this person had reduced the commitment to and amount of collaboration between departments.



## **Initiating collaboration**

When classification weakens, as happens when mathematics and science departments collaborate, then Bernstein (2000) suggests that one should ask which group is responsible for initiating the change and whether they are dominating or dominated, in other words whether they come from the top or the bottom of the institution.

Furthermore, collaboration between departments is unusual (Wilson *et al.*, 2015) and thus it is important to understand why schools began to collaborate.

Each collaboration came as the response to a different stimulus. At School A AM, as part of Cambridge University's Millennium Mathematics project, was asked to find a teacher of another STEM subject within the school and develop a way of working together. In School B the academy chain and the new building encouraged integrated teaching. At School C it was having a new building designed to encourage collaboration and seeing what they could devise as a result. At School D there was external funding channelled through a deputy headteacher. In School E the departments were moved together by the headteacher to encourage conversations and, as the individual teachers involved got on well, this gambit worked. At School F the initial stimulus was a 'mathematics across the curriculum workshop' which led to a questionnaire and a response to the findings.

While most schools in England have a traditional department structure including heads of science and mathematics, it is conspicuous that three of the six collaborating schools had a non-traditional arrangement. It is also noticeable that in none of the six schools was the collaboration initiated by discussions between the heads of science and mathematics. In a study of collaborating schools in the early 1980s, Hart, Turner and Booth (1982) similarly found that collaboration was more likely when science and mathematics were in a faculty.

The decisions both to organise the school in a non-traditional way – in larger faculties rather than departments – and then which subjects to group together, were clearly taken at a senior level in the schools. In School B the decision firstly to organise as faculties and then to collaborate appeared to have come from beyond even the principal, from the academy chain and sponsors; in Schools C and E the decision came from the headteacher or senior leadership team. Similarly in Schools D and F, the impetus behind the collaboration came from the senior leadership team in the school rather than from individuals in the departments. To answer Bernstein's question, therefore, in each of these five schools the impetus for collaboration came from a dominating rather than a dominated group and from the top of the institution. Thus the collaborations, at least in five cases were less a free choice by individual science and mathematics teachers than a result of compulsion by those in authority.

School A is a notable exception as the collaboration was initiated by AM who, as an Advanced Skills Teacher, was working outside the traditional department and school hierarchy. It was apparent during the interview with ATL that AM was highly respected and valued by the school leadership and consequently tended to be allowed significant freedom to experiment with different ways of working, with the collaboration with the science department forming part of that experimentation.

That collaboration was not, at least in any of these six cases, initiated by the heads of science and mathematics is perhaps not so surprising given Ball's (1987) observation that relations between heads of department are not always peaceful and can be fraught, with battles for resources and power. If a relationship is already fraught, it would be likely that innovations or changes in teaching practices, identified by Ball as tending to enhance certain groups over others, would be viewed with suspicion and resisted.

The question therefore arises as to why the impetus to collaborate came in five cases from those in authority. One interpretation is that teachers have minimal interest in working across departmental boundaries unless they are compelled, or at least strongly encouraged, to do so – making AM an unusual exception. It could instead be that the boundaries are so significant, the insulation, in Bernstein's (2000) terms, so strong, that it is extremely challenging for individual teachers to cross them, with research by Frade et al. (2009) showing that the boundaries are indeed difficult to cross. The data suggest that a high degree of support from senior leaders is required in order for collaboration to succeed, with the majority of participants suggesting senior leadership support as essential for collaboration. This interpretation is supported by Straw, MacLeod and Hart (2012) who found that senior leadership commitment was essential for interdisciplinary STEM activities to succeed. The need for senior leadership support in order to change the working practices of the school has been previously shown by Ball (1987). From this limited data set it is not possible to answer definitively why the impetus was usually from higher up the school; further work in collaborating schools would be required to do so.

## **Discussion**

Looking across the descriptions of the collaborations it is possible to see that in spite of all the barriers to collaboration theorised by Bernstein (2000) and documented by Venville *et al.* (2002) and others, many of which were in evidence in these six schools, it is possible for collaboration to develop between school science and mathematics departments. Teachers in each of these six schools had found different ways to circumvent the barriers which undoubtedly exist and they show both that it can be done and that there are a variety of styles or ways to collaborate.

### ***Response to a stimulus***

It is noticeable that in each of these six cases there was an external stimulus which catalysed the start of the collaboration. In some cases the stimulus was external to the school, in some cases external to the departments, but none of them had begun simply because a science and a mathematics teacher decided to work together. This is not to say that collaboration could not begin spontaneously elsewhere, but that it did not in any of these cases. Wilson *et al.* (2015) likewise argue that external support is frequently a factor in building and maintaining collaborative practice.

### ***Finding meaningful connections is not straightforward***

Zhang *et al.* (2015) suggested that it should be relatively easy for teachers to find points of overlap in the content of the two subjects, and they are far from the only authors to make such a suggestion. However, all the teachers interviewed were experienced and none of them had found making connections across the subjects straightforward. At School A, AM and AS had taken some minutes to recognise angles of incidence and reflection as an example of symmetry. At School C, teachers feared being asked to make connections in front of a class as they were likely to find it challenging. In three of the four schools which had tried interdisciplinary projects (Schools A, B and C) the teachers had reservations about the science context of the project. In Schools A and C they clearly deemed their science contexts rather simplistic, at School B they had included the same science context, healthy eating, a number of times over the two years of integrated teaching.

Although Zhang *et al.* (2015) suggest that it should be relatively easy for teachers to find points of overlap in the content of the two subjects, Williams *et al.* suggest that working across department and disciplinary boundaries requires confronting ‘differences in understandings of knowledge, discourse and practice’ (2016,

p.6), which is far from easy. Indeed, the teachers in this study had found writing meaningful interdisciplinary projects to be extremely challenging. None had used published resources; all the projects had been written by the teachers in the schools. The teachers in Nelson and Slavit's (2007) study similarly found it challenging to identify common ground.

Teachers in all four schools which had tried some interdisciplinary teaching also expressed concerns about the rigour or the context of the science and mathematics which could be covered in joint projects. These concerns relate to difficulties identified by Williams *et al.* (2016), who argue that there is nothing obvious to exchange when science and mathematics teachers work together, or no clear benefit to both sides. In consequence it is difficult to define project outcomes which are meaningful and useful to both subjects, difficulties clearly expressed by the teachers in this study.

### ***Valued professional learning***

The outcome of collaboration most valued by teachers was their own professional learning. For example, AM explained that:

For things like rearranging equations, we do that in maths, [pupils] do that in science, actually it's the same thing and whilst I think I'd previously seen this as blindingly obvious, that it's the same thing, I now think that pupils haven't. [AM]

For AM, collaboration led to the realisation that students do not necessarily see the parallels between what they are asked to do in separate subjects.

Other valued professional learning included understanding of the 'other' department's curriculum, teaching and decision making. Informal conversations were pointed to by many teachers as being the most fruitful in enhancing their knowledge of the differences in approach.

For some teachers, greater understanding allowed for curriculum planning which took more accurate account of what students had, and had not, covered previously. For example: *'We realised that we were teaching things in science that they hadn't encountered in maths at all'* [FS]. Such knowledge allowed the science team at School F to plan for the teaching of skills that students will not yet have come across in mathematics. It is important to realise that FS had been teaching for several years, and was a head of department when this collaboration began, suggesting that knowledge of the mathematics curriculum is relatively rare among science teachers. This is not in any way to disparage science teachers' knowledge, as having the knowledge and appreciating the connections across just one subject is recognised as being demanding and evidence of expert practice (Turner & Rowland, 2011); seeing connections across two disciplines when the teacher probably teaches in only one is clearly challenging. Difficulty in seeing connections between the subjects is thus a significant barrier acting against collaboration which should not be ignored.

### ***Collaboration can be fragile***

In four of the schools (A, B, C & D) it was reported that there was less collaboration taking place than there had been in the previous year. Thus even in schools which have managed to overcome the barriers and begin to collaborate, that collaboration is fragile and at risk. The time it takes to collaborate set against teachers' workload was suggested by some as a reason for not collaborating. Of all the collaborations, projects were the most time consuming, so perhaps it is no coincidence that the schools where the level of collaboration had reduced were those where projects and interdisciplinary teaching were the major part of the collaboration. In four of the schools there was a key person who was either the driving force behind the collaboration or who was the main person involved with organising it. In Schools C and

D this key person had left and in School D the collaboration had stopped completely, and in School C reduced considerably, as a direct result of their departure. In School E the head, who had been behind moving the departments together and encouraging them to collaborate, was due to retire and ES and EM were not sure if the collaboration would continue in the same way with a new head.

## **Conclusions**

This study arose in response to calls for further research into how science and mathematics departments can collaborate (Osborne, 2011). We have explored why science and mathematics teachers begin to collaborate, what those collaborations look like in practice and how teachers from different departments communicate. We have shown that a valued benefit from collaborating is the professional learning arising from interactions with teachers from another department.

This study was unusual in not being a follow-up to a specific intervention and studying schools where collaboration began organically. It is, however, notable that in all of the schools there was some factor external to the science and mathematics departments which stimulated the start of the collaboration. In none of the schools did the collaboration arise spontaneously due to science and mathematics colleagues deciding to work together. In some cases the stimulus was external to the school and in some cases external to the department, but never did it come solely from within the departments themselves. This is not to say that collaboration could not arise from within departments in other schools, but that in each of the six case studies presented here teachers pointed to factors external to the departments in describing how collaboration began.

All of the collaborations were regarded as fragile by those involved, with four schools seeing a reduction in joint work compared to the previous academic year and

one awaiting a change in school priorities with a new head. When school priorities change such that previous support for collaboration is removed or reduced, it seems to collapse rapidly.

Although relatively small in scale, this study has shown that it is possible for mathematics and science teachers to collaborate. This study did not explore, however, whether or how instructional and teaching practices changed as a result of collaboration. There were some hints in the data, for example in School E and F the science teachers talked about how knowledge of the mathematics curriculum helped them to know when students were unlikely to have met mathematical content and to plan to teach it themselves if was needed. It would be also interesting to explore whether and how any changes in teaching practices impacted on students' confidence in using mathematics in science, noted by some authors as being low (for example, Dodd & Bone, 1995).

Further work is required to examine the actual benefits and learning gains for students from different styles of collaboration, in order to explore whether they are the most profitable use of teachers' time. It is unknown exactly what students gain from more detailed and time consuming collaborations such as projects. This lack of knowledge about what students gain from collaboration has also been highlighted by Honey *et al.* who argue that there is little research 'on whether more explicit connections or integration across the disciplines significantly improves student learning, retention, achievement, or other valued outcomes' (2014, p. 22).

It is the case, however, that neither collaboration nor finding meaningful connections between the school subjects is as straightforward as is sometimes assumed. This can be seen in the difficulties that were reported in finding suitable contexts for both projects and the visiting expert. Finding these points of connection took time and was often frustrating. Suggesting it is relatively easy for teachers to find points of



overlap presupposes that teachers are able to see connections between the disciplines, when to do so would require content knowledge of both subjects and an understanding of the connections both within and between them. Having the knowledge and appreciating the connections is recognised as being demanding and evidence of expert practice in just one of the subjects (Turner & Rowland, 2011); seeing connections across two disciplines when the teacher probably teaches in only one is clearly not as straightforward as many authors assume.

Science and mathematics departments often operate largely independently of one another and, furthermore, departments are often in competition with each other for resources including money, physical space and high achieving students. Such competition can lead to an often uneasy, or even hostile, relationship between heads of departments (Ball, 1987). From the collaborating schools which participated in this study, it would appear that there are two main ways in which such issues can be overcome. The first is through senior leadership team involvement, with leadership teams or headteachers encouraging or compelling collaboration. One way of facilitating collaboration is through the creation of science and mathematics faculties, as seen in three of the schools in this study. Such faculties are not guarantees of collaboration, however, in the absence of continued support. Furthermore, it is important to consider what might be lost as a result of creating larger teams. In many English state secondary schools each department can have in excess of 12 teachers, thus the faculty will contain at least 24 teachers. Such a large group could lead to the loss of a feeling of nurture and support that often exists within a department (Burn, Childs, & McNicholl, 2007). Bernstein (2000) argues that it is not possible to have both a strong department culture and strong relationships across the school. It is not clear that it would be in the best

interest of teachers or students that departmental relationships be broken down in favour of cross-department ones.

The second way to address the issues is through informal conversation in a pre-existing relationship. To have discussions which reveal one as lacking knowledge it is necessary to trust the person with whom one is conversing. As such, forcing these types of conversations is unlikely to be successful and knowing the person a necessary prerequisite to fruitful conversation. We have shown that conversations to better understand the mathematics curriculum were a good investment of time for science teachers and produced valued professional learning. Conversations can help science teachers to understand students' difficulties in using mathematics, and help them in planning to take effective account of those difficulties. Taking effective account of what students already know is not a new idea in science education, as demonstrated by the large number of studies about misconceptions, but it is just as important to take account of what students understand and can do mathematically in science.

Collaboration, therefore, is possible but challenging. There are significant barriers which must be overcome in working together, not least that it is a departure from established practice in most schools. This study further emphasises the important role that senior leaders' support plays in beginning and maintaining collaboration. Indeed, any strategy for science-mathematics teacher collaboration should involve senior leadership support to increase its likelihood of success. Teachers valued the professional learning which resulted from talking to colleagues from other departments, but further work is needed to explore if and how their classroom practice changed as a result, and if such changes resulted in improved outcomes for learners. If the STEM agenda is to be enacted in schools through collaboration there is a very long way to go.

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## Appendix 1

### Questions to the mathematics/science teachers

- [Question about their specific collaboration.]
- Could you tell me about some of the things that you have done to implement that?
- How did that get started?
- Why do you do this – it's unusual compared with many other schools?
- What are the benefits to the [maths/science] department of working in this way?
  
- What differences does your [collaboration] make:
  - to you and your teaching
  - to the students
    - have you noticed any differences in how they approach [maths/maths in science] as a result?
  - to the maths teachers
  - to teachers in other departments
  - to the whole school?
  
- How much time do you think doing this takes?
  
- What are the difficulties in trying to do [your collaboration]?
- Is there anything which doesn't get done or is harder due to [your collaboration]?
  
- How does the [mathematics/science] department collaborate specifically with the [science/mathematics] department?
- Is that collaboration any different to work done with other departments?
- How much time does it take to collaborate with [science/mathematics]?
- What links do you, personally, see between mathematics and science?
- Is everyone in the [maths/science] department involved?
  - Why not?
  - What do you think they lose for not being involved?
- Has this caused any difficulties within or between departments?
- What do you think the next 5 years will look like in terms of collaborating with science?
- Does the senior leadership team here support departmental collaboration?
- What, if anything, has been done to support working across departments?
  
- What differences do you see in the way in which specific topics are handled within mathematics and within science?
  - Eg data handling, graphing, ratio and proportion
  - Does [your collaboration] help you to understand the differences?
  
- Is there any further collaboration which you would like to see between specifically maths and science?

- What might you need to make it happen?/What might be the barriers?
  - Are there any specific difficulties to maths and science collaborating?
  - Any specific benefits to them collaborating?
- 
- The new draft KS4 national curriculum for mathematics states that pupils “should apply their mathematical knowledge to science”. What do you think schools can do to ensure this happens?
  - The new KS4 national curriculum for science specifies quite a lot of mathematics which has to be used in science contexts. Do you have a view on increasing the amount of mathematics within the science curriculum and in science GCSE exams?
  - Will your collaboration help you to implement such changes, do you think?
- 
- Have you done anything like this before somewhere else?
  - If you wanted to set up something like this in another school, who would you speak to?
  - What advice would you give to someone in another school who wanted to set up a similar collaboration?

## Questions to the member of the senior leadership team

- In your school the mathematics and science departments collaborate. This is quite unusual in England. Does the senior leadership team here support the idea of departmental collaboration?
- What, if anything, has been done to support the collaboration?
- Why did the maths and science departments start collaborating?
- What links do you, personally, see between the subjects?
- What differences do you think collaborating makes
  - to the students
  - to the teachers
  - to the whole school?
- How much time do you think the collaboration takes?
- Is everyone in the maths and science departments involved?
  - Why not?
  - What do you think they lose for not being involved?
  - Has this caused any difficulties within the departments?
- What are the downsides to the science and maths departments collaborating?
- Is there anything which doesn't get done because of their collaboration?
- What do you think the next 5 years will look like?
- Is there any further collaboration which you would like to see between maths and science?
- What might you need to make it happen?/What might be the barriers?
- Are there any other departmental collaborations at [your school]?
- Does the school do anything else which is integrated, curriculum-wise?
- Several institutions now offer a physics with mathematics PGCE course. Would you consider employing someone to teach across the two subjects?
- The new KS4 national curriculum for science specifies quite a lot of mathematics which has to be used in science contexts. Do you have a view on increasing the amount of mathematics within the science curriculum and in science GCSE exams?
- The new draft KS4 national curriculum for mathematics states that pupils "should apply their mathematical knowledge to science". What do you think schools can do to ensure this happens?
- Will collaboration help you to implement such changes, do you think?
- What advice would you give to someone in another school who wanted to set up a similar collaboration?



