Problematising Integration in policy and practice

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ABSTRACT

Many arguments have been advanced for the integration of mathematics and science education including: economic arguments; integration being logical; being engaging; increasing transfer; increasing conceptual learning and that the real world is interdisciplinary in nature. This chapter explores some of the issues and contradictions with each of these arguments drawing on Bernstein's theory of boundaries. An example of integration in the policy sphere (STEM policy in England) is first discussed and some of the tensions arising are explored. Crossing the boundary is more challenging than is often implied in discussions of integration with issues of epistemology, status and language needing to be addressed. Further, integration may not yield the expected benefits and could even decrease conceptual learning in the disciplines. The author argues that the policy context should be considered when advocating integration and that careful consideration be given as to whether integration is genuinely the most appropriate solution to identified educational issues.

INTRODUCTION AND DEFINTIONS

It has been claimed that mathematics is essential to science. This is not an uncontested notion, and the nature of the mathematics required for different branches of science varies considerably, but there is little disagreement that at least some mathematics is necessary to do science. Partly due to this dependency there have been calls for mathematics and science education to work more closely together, often described as integration.

Defining integration is problematic. Berlin and White (2012) note a plethora of terms in the literature which are used to refer to what they would describe as integration: integration; connection; co-operation; co-ordination; correlated; cross-disciplinary; fused; interactions; interdependent; interdisciplinary; interrelated; linked; multidisciplinary; trans-disciplinary; unified. In the UK the term cross-curricular is also used. For some authors integration means the traditional discipline boundaries are blurred or even lost, while for others integration retains boundaries but stresses the interactions between disciplines (Lederman & Niess, 1998). The lack of clarity means that while 'integration' might suggest mathematics and science are taught in the same classroom by the same teacher at the same time, a variety of other meanings are evident in the literature, with authors not always articulating exactly what they mean by any of the terms above. To make matters more challenging, not all science educators refer to 'mathematics', with some instead using the terms 'numeracy' or 'quantitative skills.' The use of neither of these terms is well-delineated. In this chapter I am using the term integration to mean crossing the boundary (the meaning of boundary is discussed below) and bringing mathematics and science teaching together in some way; describing or theorising the exact nature of that integration I will leave to others.

Among the anglophone nations mathematics-science integration is increasingly discussed as STEM (science, technology, engineering and mathematics) education. However, internationally STEM rarely means a programme of technology education (Williams, 2011) and in the UK neither does it include engineering at school level (Wong et al, 2016). McComas and Burgin (2020) similarly note the tendency to use STEM to refer to science and mathematics, ignoring the T and the E. Thus, while some of the literature that I will draw on in problematising the notion of mathematics-science integration focuses on STEM integration, rather than specifically mathematics and science integration, in practice these are often almost identical.

I begin the chapter with a brief discussion of Bernstein's (2000) theory of boundaries. I then turn to an example of integration in a policy context – the STEM policies and initiatives in England. This is an unusual example as although the mathematics and science education communities worked closely together in formulating policy during this period, there was no call for science and mathematics teachers in schools to do the same; in fact government policy at this time strongly promoted clearly delineated school subjects, particularly at secondary level. As the government policy which I am discussing relates to secondary (11-16) education, that is the focus of this chapter. The arguments may be somewhat different were primary education in view. I then consider six reasons which are given for integration. I will discuss some of the problems and contradictions in these arguments.

BACKGROUND THEORY – BOUNDARIES

In this chapter I will draw on the theories of boundaries (Bernstein, 2000) to explore some of the issues with the arguments for curriculum integration of mathematics and science.

Bernstein argues that 'A can only be A if it can separate itself from B' (2000, p. 6). To achieve such separation requires boundaries around the separate entities, in this case around school subjects or departments. These boundaries have a significant impact on the relationship between mathematics and science, in schools and in the policy sphere (Wong, 2018). Bernstein argues that boundaries are created by, and closely associated with, the operation of power. He argues that for categories (subjects) to be differently specialised from each other they need a space in which to develop their unique identity. This space is not within the subject itself, but in the distance which separates one subject from another, which he terms *classification*. In order to be differently specialised 'they must have a space in which to develop their unique identity, an identity with its own internal rules and special voice' (p. 6).

In other words, the identity of one subject is reliant on it being different from, separated from, insulated from another subject. 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 tell where one ends and the other begins and they are in danger of losing their unique identity.

Newman argues that these borders and boundaries 'are […] there to be crossed. From the moment they are established, there are always groups who have an interest in finding ways to move beyond the barrier (2003, p. 14). There is, indeed, a long history of authors and researchers calling for the integration of science and mathematics (Berlin & Lee, 2005). However, Newman cautions that 'crossing the border does not always bring the expected benefits' (2003, p. 14).

Bernstein (2000) suggests that when classification changes from strong to weak or vice versa, as is the case when departments or subjects collaborate or integrate, we should always ask whose interests are served.

The subjects of mathematics and science in schools are insulated in many ways including by differences in discourse and language, by specialised teachers, by specialised teaching spaces and support staff (technicians), the nature of the curriculum, the asymmetric dependency between mathematics and science, and blaming the mathematics department for students' difficulties with mathematics in science (Wong & Dillon, 2020).

INTEGRATION IN A POLICY CONTEXT: STEM EDUCATION IN ENGLAND

In this section I will briefly discuss a specific example of mathematics-science integration in the policy sphere: the STEM strategies in England in the first decade of this century.

A two-phase qualitative study was carried out with an analysis of government documents followed by interviews with 21 long-standing and acknowledged key contributors to the science and/or mathematics education discourse in England, including 11 science educators, 8 mathematics educators, an engineering educator and a retired civil servant. The aim was to try to understand the purposes and underlying philosophies of STEM policy in England in the period 2002-2014. For further details of the methods see Wong et al (2016).

Policy is often forgotten in education research, but policy provides the context in which schools operate (Maguire, Ball, & Braun, 2012) and therefore a better understanding of policy leads to better understanding of practice in schools.

The economic argument

Calls for a greater focus on science and mathematics education often arise from concerns about science more broadly (Wong et al, 2016). In the early 2000s, the UK government was concerned that the supply of high quality scientists and engineers should not be a constraint on future research and development (R&D) and innovation performance, due to the high importance such activity had for the economy. They commissioned a review by Sir Gareth Roberts (2002), at the heart of which was a fear that the country would become less economically competitive unless changes were made. The actions advised included many directly related to mathematics and science education and led to a series of STEM initiatives. The economic drivers behind education policy were widely acknowledged for the STEM initiatives; the majority of those interviewed stated that the reasons why STEM is promoted and was strongly funded by government are economic at heart.

Mathematics and the sciences were the subjects deemed most significant and received the most funding. A key focus and performance indicator for STEM in England was the number of students choosing physical science and mathematics subjects post-16. Compulsory education ends at 16 in England and for the majority of students there are no mandatory subjects after that age. Consequently, numbers of students studying mathematics in upper secondary education are low compared to the OECD average (Hodgen et al, 2010). There are a number of different courses on offer for post-16 students, but the focus of the STEM initiatives was to increase the numbers choosing mathematics and science A-levels, the most widely followed pre-university qualification. This preoccupation with A-level numbers was noted by the majority of the participants.

Even within science, biology was seen as a lower priority. At least part of the suggested reason for this was that the numbers studying biological sciences at both post-16 and university level were considerably higher than in the other science subjects. However, one participant pointed out that ‘biology is actually becoming more and more and more important in economic terms as well as general educational terms’ (quoted in Wong et al, 2016, p. 2359) such that bioscience could be funded more highly in future. In other words, the higher status of the physical sciences and mathematics are in part about concerns around numbers of students but also about perceived economic importance. A key difference between policy in England and in some other nations is that these skills were deemed to be developed through the disciplinary study of mathematics and science, particularly physics. There was no push for interdisciplinary teaching, indeed it was actively discouraged.

Diversity and high status students

The focus on A-level numbers also ensured a focus on only some students, as in England progression onto A-levels is only possible with high enough grades in the GCSE exams taken at age 16. For example, one science educator noted that:

> *From the point of view of the government [STEM] is about macro-economic policy. So it is driven by a thesis that says for an advanced country like this one our economic future lies in high-tech advanced technology, using the products of science, and in order to do that you need a technologically educated workforce. And therefore you need good people with qualifications in science and mathematics.* (Quoted in Wong, 2018, p. 197)

The identification of the need for 'good people' shows that this set of policies is aimed at those who will be likely to get high grades in science and mathematics qualifications, not at all students. For these 'good people' to be recognised requires ranking and ordering; such recognition is based on national curriculum tests and is highly unlikely to be socially just (Apple, 1993; Archer et al, 2016). The perceived need for a supply of people (and there may not actually be a shortage of qualified people (Smith & White, 2019)) to be part of a technologically educated workforce becomes a target to increase the numbers of students studying STEM subjects in post-compulsory education and thus a driver in science and mathematics education policy. When asked about the aims, purpose and achievements of the STEM initiatives, three-quarters of the respondents referred to an increase in numbers of students choosing to study A-level sciences and mathematics and, subsequently, STEM subjects at undergraduate level. Therefore, the additional financial resources from the national STEM initiatives went to high status subjects to help them attract high status students. According to Goodson, 'the close connection between academic status and resources is a fundamental feature of our educational system' (1995, p. 173), but it is not a hallmark of a system which is socially just.

Not all interviewees found the emphasis on high-status students comfortable, with both science and mathematics educators expressing reservations about both this focus and the curricula changes subsequently introduced.

Indeed, in the early STEM documentation it is possible to see an awareness of the problem of a lack of diversity in STEM. For example, the Roberts' (2002) review recommended that action was required to improve both the number of girls and women and to address the under-representation of ethnic minorities in STEM. In the 2006 STEM programme report (Department for Education and Skills) 1 of the 17 recommended actions relates to diversity. However, the later documentation makes no mention of diversity. While virtually all interviewees mentioned improving the numbers of young people choosing to continue to study STEM subjects at some level, only two mentioned the need to increase the diversity of those people by increasing numbers of women and ethnic minorities studying STEM subjects, suggesting that any early aims to increase diversity were not operationalised, at least by 2014 (Wong et al, 2016). Since then, however, the government has part-funded research by the Institute of Physics into improving the gender balance in physics A-level; for more than 30 years only a fifth of those taking A-level physics have been female (Institute of Physics, 2017).

Risk, benefit and asymmetric dependency

England has had a national curriculum since the late 1980s and this curriculum has always consisted of discrete subjects. The possibilities of coordination were ignored in the creation of the original curriculum (Orton & Roper, 2000) with the development of the mathematics and science curriculum operating in separate channels (Wong, 2018). However, while it may appear obvious to a science educator that there should be links to the mathematics curriulcum, mathematics links to far more subjects than just to science. One of the mathematics participants described this as: 'your Venn diagrams look different' (quoted in Wong, 2018, p. 217).

Many participants who were mathematics educators were concerned that for mathematics to be seen as prioritising links to science could be perceived as privileging some reasons for studying mathematics over others. Perhaps worryingly for the science education community, some mathematics educators suggested that for mathematics to be part of STEM could be seen as ignoring the needs of the majority of school students as science could be presumed to be for only the highest-achieving students. Given the focus of the STEM initiatives on high attaining students, this could be seen as a valid concern. As there is no part of science which does not fit within STEM, these tensions were not present for science educators in the same way (Wong et al, 2016). Additionally, mathematics educators were concerned that mathematics could get lost in STEM as it was seen to have a science focus.

Wong and Dillon (2019) argue that as science is dependent on mathematics but mathematics is not dependent on science there is an asymmetric dependency between the two subjects. This asymmetry of dependency, is rarely, if at all, discussed in the education literature and yet it is critical in understanding the relationship between the disciplines. The asymmetry of dependency means that when science and mathematics work together more closely – in Bernstein's (2000) terms, the classification weakens – there will tend to be greater benefits for science from such collaboration. This insight comes directly from asking, as Bernstein (2000) suggested, who benefits from the change in classification.

Thus in the STEM policy context, perhaps unsurprisingly, the economic argument was dominant. Despite the bringing together of science and mathematics under the same umbrella policy – STEM – there were very limited calls for science and mathematics teachers in schools to collaborate or integrate their teaching. Indeed, mathematics educators were wary about close involvement with STEM, seeing risks for mathematics education in close association with science.

REASONS TO INTEGRATE

In this section I will discuss six arguments which are advanced for integration. Although the boundaries are challenging to cross, Newman (2003) argues that as soon as boundaries are established there are groups who want to find ways to move beyond the barrier. In the case of mathematics and science integration there are several reasons given for doing so. These include: the workforce argument (e.g. Millar, 2020); that there is overlap such that integration is logical (e.g. Frade et al, 2009); that it will lead to an increase in engagement (e.g. Venville et al, 2002); that it will increase transfer (e.g. Honey et al, 2014); that it will increase conceptual learning in the disciplines (e.g. Reynante et al, 2020) and that the real world is interdisciplinary in nature (e.g. Venville, 2002). I will consider some of the problems with each of these arguments.

The workforce or economic argument

This argument is based on the idea that in bringing mathematics and science teaching together, students will be able to develop desirable skills. This may be framed as skills required for the national interest (e.g. Wong et al, 2016) or to increase students' employability (e.g. Honey et al, 2014). The economic argument is favoured by many governments, at least in the English-speaking west (Millar, 2020). Millar (2020) argues that this is an instrumental argument for interdisciplinarity, where other arguments are more conceptual.

Defining what skills students learn through integrated teaching is not straightforward. In subjects learning is evaluated in terms of conceptual development, whereas the outcomes in integrated curricula are often poorly defined, as Venville et al (2002) acknowledge. As a result, they argue that integrated curricula do not fit well with the expectation in many countries that the school curriculum should be academically orientated towards traditional disciplines, and should emphasise written work, individual study and examinable aspects of the syllabus. In an era when clearly defined outcomes against arguably narrow subject criteria are the most highly prized in education, it is perhaps easy to see why, if integrated teaching has fuzzier aims, it struggles to gain much traction. Given how strongly established the disciplines are in schools, they propose that integrated approaches should not attempt to ignore the traditional subjects. Gao et al (2020) reviewed 49 empirical research articles focusing on interdisciplinary STEM in secondary and college education. They found that most assessemnts focused on disciplinary knowledge or affective domains, even when the program aimed to improve students' interdisciplinary skills. Thus assessemnt did not align with aims. When it is difficult to define the skills and thus to assess them one has to question whether what students are expected to learn is actually worthwhile.

Economic arguments for education, including mathematics-science integration, are not without their critics. For example, McComas and Burgin (2020) offer a strong critique of the workforce argument for integration and suggest that there are far fewer jobs in STEM than there are graduates. The economic or workforce argument goes beyond mathematics and science, with the prevailing political ideology being that education must serve the economy (Hill, 2013). Apple, in a paper discussing the purpose of national curricula, identifies a similar focus on industry and the economy in education in the US, identifying 'growing pressure to make the perceived needs of business and industry into the primary goals of the school' (1993, p. 4). Young suggests we need to see the curriculum not as 'an instrument for achieving goals such as 'contributing to the economy' […] but as intrinsic to why we have schools at all' (2014, p. 91). Thus, whether you accept either the economic or the skills arguments for integration will be related to your beliefs about the fundamental aims and purpose of education.

There is overlap in subject content

Partly this argument is a time-saving measure: in a crowded curriculum integration could lead to fewer learning standards (Reynante et al, 2020). Some authors, such as Pang and Good (2000) and Zhang et al. (2015) suggest that it should be relatively easy for teachers to find points of overlap in the content of mathematics and science. However, this is naïve for several reasons. Finding connections in another subject takes teachers beyond their knowledge base (Millar, 2020). To find points of overlap presupposes that teachers are able to see connections between science and mathematics, when to do so would require content knowledge of both subjects and an understanding of the connections within and between them. Having such knowledge and appreciating the connections is recognised as being challenging and evidence of expert practice in only one of the subjects (Turner & Rowland, 2011); seeing it across two subjects when the teacher probably teaches in only one is unlikely to be easy. Frade et al (2009) found that in practice it did indeed take a considerable investment of time for two experienced teachers to understand one another's disciplinary knowledge in sufficient depth to find overlaps in the mathematics and science curriculum. In a study of six schools with some level of integration between mathematics and science, Wong and Dillon (2020) found that all described finding points of overlap to be challenging. Such epistemological boundaries in knowledge present significant challenges for all involved in interdisciplinary projects (Millar, 2020).

However, the boundaries between mathematics and science teachers go beyond the epistemological. Bernstein (2000) suggests that where there is strong classification, teaching staff are tied to their departments and that their identity is bound up with that of the department. He gives two reasons for this phenomenon: firstly, 'the department is symbolic of their category' and, secondly, promotion comes by appropriate activities in the department (p. 10). Ball (1987) observed in practice that for many secondary teachers their subject, and their commitment to it, is a key part of their overall commitment to teaching. Being a *subject* teacher is central to the satisfactions that they achieve from their work.

Teacher identification with the subject goes beyond the enthusiasm for what they teach. Siskin noticed that secondary teachers of different departments speak quite different languages and:

> *demonstrate the distinctive vocabularies, logics, and concerns of their subject specialities in subject-specific ways […] these are more than simply idiosyncratic appearances of technical jargon; rather the discipline's language and epistemology are interwoven in the ways teachers – as subject-matter specialists – conceptualise their world, their roles within it, and the nature of knowledge, teaching, and learning […]*
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> *Even when teachers do not directly reference the subject matter, disciplinary background reveals itself in the choice of words, the structure of their arguments, or the goals they hold.* (Siskin, 1994, pp. 152-153)

Ball argues that there are differences between subjects in their views about the broader purposes of education, about how children learn and about the classroom responsibilities of the teacher and that these 'complexes of epistemological, pedagogical and education values and assumptions constitute, in each case, a subject sub-culture' (1987, p. 41). The same was found to be true in the USA (Grossman & Stodolsky, 1995).

Furthermore, there is perhaps a difference between requiring a mathematics teacher to teach science and a science teacher to teach mathematics – as might be required for integrative practice. Western democracies prize logical-mathematical thinking (Crombie, 1994) more highly than other types of intelligence (Caprara & Cervone, 2000). When this type of thinking is so valued, it could be difficult for a science teacher to admit to a limited knowledge of mathematics. Lack of knowledge of science could be seen as a lack of knowledge of science 'facts' which could be an easier thing to admit to as it does not require logical-mathematical thinking. Mathematics teachers frequently do not have a strong science background so there would be no expectation or loss of face in admitting that they do not have scientific knowledge. Science teachers are expected to be highly mathematical, even if that expectation is unrealistic, and thus admitting to struggling with mathematics could also challenge teachers' identity, perhaps that of teaching an elite subject, and status.

The consequences of all these differences are explained by Bernstein who argues that when subjects are strongly classified:

> *the staff cannot relate to each other in terms of their intrinsic function, which is the reproduction of pedagogic discourse. Where the lines of communication between staff are established by a system of this kind, there will be weak relations between staff with respect to pedagogic discourse, as each is differently specialised.* (2000, p. 10)

In other words, differences in language, discourse, culture and status between departments result in breaks in communication leading to weak relations between staff from different departments. Epistemological boundaries are significant, but they are not the only cause of the communication difficulties between mathematics and science teachers. When calling for science and mathematics teachers to integrate their teaching, the significant barriers that exist between them should at least be acknowledged.

Integration increases engagement

Engagement is a slippery concept which is hard to define (Godec et al, 2018). Fredericks et al (2004) identify three types of engagement: affective-emotional including attitudes and interest; cognitive including persistence and motivation; and behavioural including taking part in activities. Godec et al (2018) highlight that when considering engagement it is important to pay attention to the opportunities students have to engage, including how those who do not meet school expectations may find it harder to engage with science in the context of school science lessons. The same argument can also be made for mathematics education. They call for a focus on greater inclusion and social justice as part of any discussion of engagement. This is a particular issue for science and mathematics as what counts as knowledge in these subjects has often been dictated by a western, white, masculine identity, which can marginalise minorities and women (Reynante et al, 2020). Integration offers possibilities to disrupt the status quo and value different ways of knowing. However, integrated teaching would usually be undertaken by the existing teachers of science and mathematics. To truly increase diversity and inclusion would require that teachers change their beliefs about who can hold valid knowledge and, furthermore, communicate this change to the other students in the class. Godec et al. (2018) demonstrate that teachers can make such changes in their practice within the context of teaching science in the existing curriculum. Therefore, while the aim of increasing engagement is a valid one, perhaps integration of science and mathematics teaching is not the most appropriate response to a justified concern. Indeed, Holmlund et al. (2018) found that integration did not necessarily lead to a focus on inclusion of all students and argue that when equity is not explicitly addressed it is usually overlooked. It would thus seem that if an increase in social justice within the classroom is what is desired then professional development which supports teachers in changing their practice to be more inclusive might be the more successful approach.

Furthermore, expecting that integration in and of itself will lead to an increase in engagement is rather simplistic. Wong and Dillon (2020) note that teachers reported that problems with behaviour increased during some integrated mathematics science projects, suggesting a decrease in engagement. Issues with behaviour management were likewise noted as a barrier to integrated teaching by Czerniak and Johnson (2014). There are, however, few studies which specifically focus on student engagement in integrated contexts. An exception to this is a mixed methods study by Struyf et al (2019) of how student engagement varies in different STEM learning environments. They found that an integrated STEM learning environment had an initially positive impact on student engagement, compared to lessons in individual subjects. However, they suggest that this increase in engagement can be explained by a higher degree of student-centred teaching, rather than by the integrated nature of that teaching. They do, however, suggest that an integrated approach 'seems to facilitate the teachers' implementation of a […] student centred approach' (ibid, p1402). They sound a note of caution, however, that teachers' attitudes towards integrated teaching can influence their instructional practice, a finding which is echoed by Wong and Dillon (2020).

In other words, integrated teaching can indeed increase engagement, particularly in the hands of an enthusiastic teacher who is a good classroom practitioner. However, it may not be the integrated approach in and of itself which is the reason for that increase in engagement.

Integration increases transfer

In the educational literature, transfer is the use or application in one subject of knowledge learned in another. It is a contested idea with authors expressing a wide range of views as to what it is, whether it can be promoted through teaching and even whether it exists at all (Wong & Dillon, 2019). The argument for transfer is almost always that integrated teaching will improve students' use of mathematics in science; there is rarely a call for transfer of knowledge in the other direction (Wong, 2018).

Transfer as a lens to explore the relationship between school science and mathematics is problematic for a number of reasons. Expectation of transfer by science teachers (as reported by, for example, Turşucu et al, 2017 and Goldsworthy et al, 1999) leads to a deficit view of both students and mathematics teachers when the expected transfer is not seen (Wong & Dillon, 2019). Furthermore, Redish and Kuo (2015) in the context of undergraduate physics and Wong (2017) in the context of school graphing practices, argue that there are differences in how mathematics is used in mathematics itself and in science, which make straightforward transfer from mathematics to science unlikely.

The expectation of transfer is understandable; both subjects require students to manipulate numbers and use graphs, for example. However, Redish (2017) argues that in physics equations are linked to physical systems and that this adds information about how they should be interpreted. In the simplest terms, it is not possible to add two numbers if they have different units; one cannot add length to mass. Scientists use physical knowledge when applying mathematics to physical systems, which might involve knowing the limits to the numbers which can be put into an equation. For example, in the speed equation (speed = distance ÷ time) none of the values would be negative as speed, distance and time are scalar quantities which are always positive values. There is no mathematical reason why a negative number could not be introduced into the equation, but there are reasons based on physical knowledge. However, in the similar equation for velocity (velocity = displacement ÷ time) displacement and velocity are vector quantities and can be negative. Redish (2017) argues that physicists use physical knowledge in doing mathematics as much as they use mathematics in doing physics. Redish and Kuo argue that part of the 'acculturation of a physics student is learning to interpret the math physically, not to only focus on mathematical structure and manipulations' (2015, p. 567). This acculturation would not necessarily be emphasised in an integrated course and neither would it be taught in a mathematics class ready to be transferred into science.

However, the main difficulty with the argument that integration increases transfer between the subjects is that there is no evidence that it does so (Honey et al, 2014). This does not necessarily mean that transfer is not promoted by integration as transfer is difficult to evidence. It does mean that authors should be wary of using the general notion of transfer as an argument for greater integration between science and mathematics.

Integration increases conceptual learning in the subjects

Mathematics and science each contain distinct knowledge, specialized practices and particular skills (Reynante et al, 2020). Lederman and Niess (1998) argue that in mathematics and science there are different epistemologies, in other words different ways of knowing and building knowledge with the nature of science and mathematics fundamentally different. The use and importance of empirical evidence and data is a key area where the domains diverge.

Mathematics does not rely on the external world to support or falsify knowledge but on other reference points such as the importance of logic. Science does refer to the external world. The ultimate arbiter of knowledge is empirical (derived from experience) observation. Lederman and Niess argue that because of these fundamental differences, the disciplinary boundaries between the disciplines should be maintained even when they are being integrated. However, they express concern that much integrated work emphasises inquiry and problem solving. They argue that what counts as data upon which decisions can be made is fundamentally different in the two disciplines and thus attempting to combine them equally will result in a hybrid version of inquiry which is 'confused and chaotic' because 'different disciplines view the world and how one comes to know it differently' (p. 283). Instead, rather than trying to dissolve the disciplines and create hybrids we should focus on interactions between them.

Reynante et al (2020), however, argue that the clear distinctions between the disciplines could be changing. Statistics, data science and applied mathematics are considered to be part of mathematics in many classrooms even while there is an on-going debate as to whether they should properly be considered mathematics. They suggest that as these mathematical sciences increase in use it could be argued that the epistemology of mathematics now includes 'elements of epiricism' (p. 788) which blurs the boundary between mathematics and the sciences.

In spite of the possible blurring of boundaries, key differences in the conceptual ideas in the subjects remain. Wong and Dillon (2020), in a study of four schools carrying out integrated project based teaching, reported that teachers expressed concerns about the scientific and mathematical content which could be covered in joint projects. In other words, prioritising integration led to a loss of subject-specific content and learning. The longer the project, the more this issue was felt to be problematic. Williams et al. (2016), argues that there is nothing obvious to exchange when science and mathematics teachers work together; no clear benefit to both sides. In consequence it is difficult to define project outcomes which are meaningful and useful to both subjects.

This finding chimes with work by Becker and Park (2011) who found negative effect sizes for mathematics in some studies into integrated teaching of STEM, alongside often positive effect sizes for science. Reynante et al (2020) suggest mathematical learning could be reduced as there is a lower likelihood of students taking up abstract ideas when interdisciplinary learning tends to be focused on real world contexts at the expense of thinking about abstract relational ideas.

Indeed, in a wide ranging review of the literature on interdisicplinary STEM teaching, including mathematics-science integration, Honey et al. (2014) suggest that integrated approaches could impede learning by placing excessive demands on resource limited cognitive processes such as working memory and attention. Like Lederman and Neiss (1998), they express concern that integrated approaches could obscure important differences between disciplines about how knowledge is constructed and revised. They argue that there is limited research evdience as to 'whether more explicit connections or integration across the disciplines significantly improves student learning, retention, achievement, or other valued outcomes' (Honey et al, 2014, p. 22). Nine years on, evidence for integrated teaching improving student disciplinary learning remains limited.

Real world challenges are interdisciplinary

In the real world there will, of course, always be problems which require solutions which transcend disciplinary boundaries and require an interdisciplinary apporach (McComas and Burgin, 2020). For example, during the recent Covid-19 crisis the UK government had advisory committees of people with expertise in a range of disciplines including medicine, microbiology, statistics, behavour sciences, public health and epidemiology (Scientific Advisory Group for Emergencies, 2022). The nature and complexity of the problem demanded that the detailed knowledge of the practices and content of each discipline be brought together in the search for viable solutions to the evolving emergency. No one person or discipline had all the knowledge and expertise required; that an interdisiciplinary approach is required to meet such challenges is recognised in the composition of such an advisory group. Indeed, Millar argues that 'while much of the discussion of interdisciplinarity assumes that it is inherently different to disciplinarity, an alternative school of thought poses that interdisciplinarity presupposes disciplinarity such that one is integral to the other' (2020, p. 939). However, the need for a range of expertise in solving real world challenges, described by McComas and Burgin as 'thinking and working outside the disciplinary boxes' (2020, p. 826), does not mean that working on such problems is the best way to help learners gain foundational knowledge and understanding within each discipline.

Perhaps as a result of the focus on real world contexts, a common approach to integrated projects is to start with a science context to which mathematics is added (Wong, 2018, Frykholm and Glassom, 2005 and Pang and Good, 2000). Such a science-first approach can lead to concerns from mathmeatics educators that the mathematics and mathematics learning can be lost in the excitement of the real world context (Wong and Dillon, 2019). The science-first approach may help to explain Becker and Park's (2011) finding that when mathematics is taught in an integrated context with science, mathematics attainment can be lower than when it is taught separately. Nonetheless, Struyf et al (2019) found that students find the use of authentic real world problems engaging.

CONCLUSIONS

In this chapter I have discussed some of the policy discourse that emerged from the bringing together of mathematics and science in England's STEM policy initiatives. I have then explored many of the arguments given for integrating mathematics and science and have examined some of the problems with each argument.

Many of the arguments for integration in schools can be seen in the policy context, albeit often with different foci. For example, the workforce argument, or at least the economic argument, is seen in England's STEM policy. However, it is expressed as a focus on student numbers in physics and mathematics rather than specific skills. Physics and mathematics as they stand are perceived to develop skills that are required by the country. This perhaps reflects the status and value western democracies place on logical-mathematical thinking (Caprara & Cervone, 2000). It also reflects the emphasis in STEM policy on what the country was perceived to need, rather than what might be of benefit to individual students in their future lives.

Desire for an increase in transfer was seen in the STEM government data, although it was not strongly present. Most discussions of transfer frame it as from mathematics to science but the belief among some UK policy experts was that an increase in mathematics in science would lead to greater achievement in mathematics assessments (Wong, 2019). It was, in any case, not an argument for greater integration in schools.

The aim of an increase in engagement is evident in both the literature calling for an increase in integration and the STEM policy documentation from England. The focus on engagement from the policy documentation is strongly on numbers of high status students ('good people') choosing to study science. In the focus on high status students, calls for an increase in diversity are lost or diluted and the STEM initiatives become, in effect, a call for more of the same type of student rather than an attempt to attract students from a wider range of backgrounds.

Neither the ‘overlap so integration is logical’ nor the ‘real-world challenges are interdisciplinary’ arguments are seen in England’s policy documentation and are rarely present in the interview data. This reflects the government focus on a curriculum made up of discrete subjects (Young, 2011), with the knowledge that students are expected to know and that schools are expected to teach laid down in detail in the national curriculum. The most recent curriculum, being developed as the research was carried out, is a deliberate and determined move (Young, 2011) away from a curriculum based on the competencies or skills which are often the basis of interdisciplinary projects.

Wong and Dillon (2020), in a study of mathematics-science collaboration in schools, found that for teachers to engage in integrated (or cross-departmental) practice required the endorsement of, or even promotion by, school leaders, a finding echoed by Struyf (2019). The leaders are influenced, in turn, by the national context in which they operate. Where neither input regulation (such as national curricula) nor output regulation (such as measurement of school performance by attainment data, external inspections and audits) (Priestley et al, 2021) value integrative practice it makes it hard for school leades to supoort it. Indeed, Wong and Dillon (2020) found that the collaborative practice was both rare and fragile, collapsing rapidly when support was removed. The balance of risks and benefits for individual schools and teachers in engaging in integrated teaching will be strongly influenced by the external context in which they operate and which educational outcomes are valued within that context. Fensham (2009) argues that the political and cultural context is often ignored in science education research, as is the interplay between stakeholders in school and beyond who determine the way the curriculum is enacted. Thus, the opportunities for teachers to engage in integrated practice will be constrained by school leaders. Decisions by school leaders about the balance between the risks and possible benefits of integration will be strongly influenced by the policy context in which they operate. Therefore, any promotion of integrated practice should take into account the policy context in which schools operate.

Given the difficulties with the arguments for integration that I have outlined, should science and mathematics educators persist with integration and is it a worthwhile educational aim? The answer to this question will depend on the beliefs held about the aims of education, the policy context, the amount or proportion of time that will be spent on integrated teaching and, in particular, what issue the integration is intending to address. There are many and significant barriers for science and mathematics teachers to cross in order to integrate their teaching. Careful consideration should be given to the problem that integration is attempting to solve and whether integration is likely to be the most effective approach or response.

ADDITIONAL READING

Reynante, B., Selbach-Allen, M., & Pimentel, D. (2020). Exploring the promises and perils of integrated STEM through disciplinary practices and epistemologies. *Science and Education, 29*, 785-903.

Wong, V., & Dillon, J. (2019). 'Voodoo maths', asymmetric dependency and maths blame: why collaboration between school science and mathematics teachers is so rare. *International Journal of Science Education, 41*(6), 782-802.

Wong, V., & Dillon, J. (2020). Crossing the boundaries: Collaborations between mathematics and science departments in English secondary (high) schools. *Research in Science and Technological Education, 38*(4), 396-416. doi:DOI: 10.1080/02635143.2019.1636024

Wong, V., Dillon, J., & King, H. (2016). STEM in England: meanings and motivations in the policy arena. *International Journal of Science Education, 38*(15), 2346-2366.

KEY TERMS AND DEFINITIONS

A-levels

Post-16, pre-university qualification taken by students in England and Wales. Usually only 3 subjects are chosen for study at this stage.

Asymmetric dependency

Science education is dependent on mathematics, mathematics education is not dependent on science (or at least is less dependent on science), thus the dependency is asymmetric.

Collaboration

In this chapter I am using this term to mean any form of working together by teachers from mathematics and science disciplinary backgrounds and school departments which focuses on teaching and learning.

Secondary education

Schooling for 11-18 year olds. In England, education is compulsory up to the age of 16; post-16 a variety of courses are on offer, including A-levels.

STEM

Science, technology, engineering and mathematics.

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