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STEM in England: meanings and motivations in the policy arena

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ABSTRACT

STEM, an acronym for Science, Technology, Engineering and Mathematics, is widely used in science education. There is confusion, however, as to its provenance and meaning which is potentially problematic. This study examines the purpose of STEM practice in education in England and asks if there are differences in perceptions of STEM between science and mathematics educator stakeholders. The study's contribution to the literature is its unusual focus on those who were responsible for making and enacting national STEM policy. A two-phase qualitative approach was followed comprising an analysis of government documentation together with semi-structured interviews with key contributors to the science and mathematics education discourse. Findings suggest that there is a disconnect between the interpretations of the science and mathematics educators with a danger-advantage dichotomy to participation in STEM being perceived by the mathematics educators. Early aims of the STEM agenda, including increasing diversity, gave way to a focus on numbers of post-16 physics and mathematics students. We conclude that if the term STEM is to continue to be used then there is a need for greater clarity about what it represents in educational terms and a wider debate about its compatibility with the aims of science education for all.

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From past to present: the story of STEM

STEM has become a key driver in science education with many projects funded by the European Union coming under the STEM banner (European Commission, 2016), yet there is a lack of clarity regarding its history and a variety of different meanings are ascribed to it. Part of the reason is that it is an acronym with a vague history. In this section, the history of STEM will be traced and links to wider discourses in education examined. We begin by looking at STEM as a single construct as it is a well-known and frequently used term, however we will also tease out whether seeing it in this way is always helpful.

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STEM usually refers to Science, Technology, Engineering and Mathematics, but to some it is Science, Technology, Engineering and Medicine and for many outside the 'STEM community' it means nothing (Breiner, Harness, Johnson, & Koehler, 2012). The first use of the term is often credited to Judith Ramalay at the U.S. National Science Foundation (NSF) in 2001 who re-ordered the term then used by NSF, SMET (Breiner et al., 2012; Mohr-Shroeder, Cavalcanti, & Blyman, 2015; Sanders, 2009). However, references to STEM used to refer collectively to those four disciplines can be found in published material several years prior to that date, such as Robinson (1994). In short, the origins of either STEM or SMET seem to be lost. The original intention in bringing these disparate disciplines together is likewise unclear. Even the UK National STEM Director has admitted not understanding the logic behind it: 'Whatever may have led us to cluster these subjects together, it cannot be their similarities, because they have few' (Holman, 2011). The reasons for the omission of perhaps similar seeming disciplines such as medicine is likewise not clear and the lack of clarity regarding its history together with its varyingly perceived meanings are indicative of confusion and imprecision. It seems timely, therefore, to examine more closely the philosophies and purposes of STEM in education.[1]

Calls for greater emphasis on science and mathematics education are often linked to concerns about science. In England, this idea that perceived problems facing science can be ascribed to what happens in schools dates back as far as Charles Babbage in his 1830 treatise, *Reflections on the decline of science in England and on some of its causes*, where he suggests that what happens in school science and mathematics will have an impact on the state of science:

> … the tastes and pursuits of our manhood will bear on them the traces of the earlier impressions of our education. It is therefore not unreasonable to suppose that some portion of the neglect of science in England, may be attributed to the system of education we pursue.

The idea that neglect of science can be traced to education recurred 170 years later in a review conducted by Sir Gareth Roberts (2002). The review was commissioned by the UK government who were keen to improve productivity and were concerned that the supply of high-quality scientists and engineers should not constrain future research and development (R&D) and innovation performance. At its core was a fear that the country would become less economically competitive unless changes were made. The actions advised include many aimed at improvements to, particularly, mathematics and science education.

Roberts (2002) could have taken Babbage's title for his report, but instead it was published as *Get SET for success – the supply of people with science, technology, engineering and mathematics skills.* It is worth noting that the term STEM is embedded in the report title through the order in which the disciplines are given. While the origins of the acronym are also obscure in England, Roberts was clearly aware of the term. The report began a discourse of SET, which was later revised to STEM and engendered the formal STEM agenda in England.

Roberts' report was followed by four reports related to science, innovation and STEM more broadly (Department for Education and Skills (2006); HM Treasury, Department for Education and Skills, Department for Trade and Industry (2004); HM Treasury, Department of Trade and Industry, Department for Education and Skills, Department of Health

(2006); Sainsbury (2007)). In 2006, the Department for Education and the Department for Business, Innovation and Skills[2] jointly set up the STEM programme and appointed a National STEM Director. The details of this process were set out in the *Science, Technology, Engineering and Mathematics Programme Report* published in 2006. An audit was taken of the various programmes and initiatives relating to STEM which were then publically funded, leading to the *STEM cohesion programme* which was aimed at ensuring that all these initiatives were coherent and coordinated. Eleven types of activities, called Action Programmes, were identified which were needed to move STEM forwards in schools. They included teacher recruitment, continuing professional development (CPD), the curriculum and careers advice. These 'Action Programmes' each had a lead organisation from outside government which coordinated what happened. An evaluation of this programme was published in 2011.

Alongside this initiative, a high-level STEM strategy group was formed which included government ministers, civil servants and representatives from each of the lead organisations, together with other organisations such as charitable trusts, subject associations and learned societies. This group also brought together the previously separate Maths Programme Board and School Science Board.

Similar concerns about competitive advantage arose in the U.S. in *Rising above the gathering storm* (National Academies Press, 2006). This report suggested that U.S. competitive advantage in science and technology was being eroded and argued that one of the main strategies to tackle the issue would be by 'vastly improving' mathematics and science education.

A discourse of STEM is prevalent in many other countries and Williams suggests that internationally, the 'rationales for the [STEM] agenda are various but limited, and related mainly to vocational and economic goals' (2011, p. 26). The emphasis on economic arguments in and for education is not limited solely to those surrounding STEM. Ball argues that education more widely is seen as a producer of labour and skills 'as a response to the requirements of international economic competition' (2013, p. 14). Hill (2013) likewise suggests that the prevailing political ideology is that education must serve the economy.

Confusion about the nature of STEM education is, perhaps, unsurprising as it has developed from an economic rather than an educational rationale (Williams, 2011). Some in education view STEM as a collection of subjects which should continue to be taught in the traditional disciplines; others argue that as those who practice STEM in the workplace are frequently not constrained by those same discipline boundaries, the same should apply in schools (Breiner et al., 2012).

Bybee (2010) suggests that in schools, even when the term STEM is used it really means only science and mathematics. The 'T' is problematic for many and there are varied interpretations as to what it means in an educational context (Honey, Pearson, & Schweingruber, 2014), not all of them being a programme of technology education (Williams, 2011) and often referring to computers and a means of delivering instruction (Bybee, 2013).

While many prefer to observe some form of boundary between disciplines (however defined), there have been attempts to teach STEM with a more interdisciplinary approach. However, in reviewing a wide range of literature and reports, Honey et al. (2014) noted that:

> Despite the arguments for making connections across the STEM disciplines and the increased number of efforts to design learning experiences that will foster such connections, there is little research on how best to do so or on whether more explicit connections or integration across the disciplines significantly improves student learning, retention, achievement, or other valued outcomes. (p. 22)

Williams argues that the problem for teachers trying to integrate STEM is that there is an 'absence of a sound educational rationale for this combination of subjects' (2011, p. 31) which inhibits the development of integrative approaches.

In sum, the origins of the term STEM and the reasons for the inclusion of that particular set of disciplines are obscure. It is conceptualised and enacted in a variety of different ways. Yet in spite of this, the discourse of STEM is found widely in education, not only in England and the U.S.

The role of policy networks in driving STEM

The problem of increasing the numbers of students choosing to study STEM subjects at university and, prior to that, in post-compulsory schooling as identified in the Roberts' Review (2002) was deemed by the government to be difficult to solve. To develop policy to try to tackle the problem, the UK government, which covers England, Scotland, Wales and Northern Ireland, developed a policy network to advise them. Ball and Junemann (2012) argue that the UK government is increasingly using policy networks to bring new solutions to difficult problems by bringing together traditional government agencies and public bodies with private, voluntary and philanthropic organisations which have an interest in the issue at hand.

The term *policy* is commonly used but difficult to define (Hill, 2013). Ball suggests policy is 'a process, something on-going, interactional and unstable' which is often 'messy, contradictory, confused and unclear' (2013, p. 8). The term *policy network* is likewise contested and subject to several different interpretations (Ball & Junemann, 2012), but is used here to describe several interdependent actors from a number of different organisations involved in defining and delivering a policy agenda. These networks may be harmonious but they can be large and conflict-ridden with members only loosely connected. This type of policy-making is, by its nature, rather opaque. It also requires collaboration across discipline and professional boundaries. Many authors have written about collaboration (e.g. Edwards, 2011) in a very wide range of settings, but they virtually all agree that collaboration across disciplinary or professional boundaries is not straightforward.

As with all types of policy-making, there are benefits and disadvantages to networks. Involvement can help to establish relationships with the state for non-state actors, and provide a wide variety of opportunities to engage in policy conversations resulting from access to the decision-making sites of government. It can lead to the receipt of awards, honours and appointments (Ball & Junemann, 2012).

Although there are advantages in the use of policy networks, not least for those who are in them, there are also potential drawbacks. As Millar (2014) notes, many influential bodies in England have perceived interests which lead them to promote policies which prioritise science education for the 20% who go on to study more advanced academic science and resist any changes designed to address the needs of the vast majority whose science education ends at age 16.

These networks are particularly useful when the problems identified transcend organisational boundaries. As STEM, however it is defined, by its very nature transcends the majority of organisations, a network may be the most obvious means of making policy.

In summary, as with its origins and purposes, STEM policy is often confused and unclear. The issues highlighted by Roberts (2002), particularly the difficulty in attracting more young people into studying science, are seen as intractable and problematic. Often the government will turn to a network of interested parties in their search for solutions to these types of problems; such parties may not have an equal interest in all school students. These networks may be only loosely connected and there may not be entirely harmonious relations between those involved. It can be difficult to determine exactly the membership of policy networks and who is influential within them as their workings are generally opaque.

Subjects in schools

As noted by Ball (1987), Goodson (1995) and others, not all subjects in schools have equal status. One way of determining status is by whether the subject is compulsory and how many years is it studied at school. Science and mathematics are compulsory from the ages of 5–16; technology (as Design Technology) is not. In England, other measures include identifying whether there is an A-level (post-16 qualification) in the subject, by the perceived relative difficulty of those A-levels and by whether they are welcomed by universities for degrees with the highest entry requirements.

According to Goodson, 'the close connection between academic status and resources is a fundamental feature of our educational system' (1995, p. 173). Subjects with high status are more likely to attract high-status students who, for the transition at 16 to post-compulsory education, are those with high grades at age 16 (in GCSE, General Certificate of Secondary Education, examinations). Ball (1987) argues that departments in school fight between themselves like mediaeval barons for territory and power. He argues that partly what they are fighting for is access to the highest status students, particularly post-16.

England is unusual among OECD nations in that from the age of 16 students can opt to leave full time education and even those who do remain can choose which subjects they continue to study; usually they will continue with just three, known as Advanced or A-levels, from age 16 to 18 meaning that the proportion of students studying particularly mathematics beyond the age of 16 is low compared to other OECD nations (Hodgen, Pepper, & Ruddock, 2010). The low number of subjects studied by each individual also adds urgency to the fight for the highest status students. STEM in England, therefore, is situated in the context of wider education policy.

Research rationale

So far, we have suggested that the origins of the idea of STEM are unclear and that what STEM means in educational terms is contested. It is acknowledged that working across organisation and practice boundaries is challenging and many organisations were involved in overseeing STEM policy and the initiatives under the STEM banner in England.

This research aims to try to understand stakeholders' perspectives on formal STEM policy and asks what are the purposes and underlying philosophies of STEM in England? In particular, this study explores whether perceptions of STEM vary between the educators of mathematics and educators of science. Most research on STEM education has focussed on how it is interpreted in schools; this study is unique in its focus on those who were charged with making and enacting STEM policy at a national level.

Research methods

A two-phase qualitative study was undertaken to try to understand the purposes and underlying philosophies of STEM in England, through published government documentation related to the STEM initiatives and through semi-structured interviews with some of those closely involved. The focus on mathematics and science is due to the lack of clarity both about what 'T' and 'E' represent and the place of each in the STEM discourse.

The first phase consisted of an analysis of the six key government documents (shown on the timeline in Appendix 1) which detail the origins, purposes, funding, management and evaluation of the STEM agenda, STEM programme and STEM cohesion programme. These are the documents about STEM as it relates to education which were published by the Department of Education (and its predecessors) or HM Treasury between 2002 and 2011. The Roberts' review of 2002 was cited by many interviewees as the start of STEM in England, justifying this as the first report included. The 2011 Final Evaluation was the last report focused on this phase of STEM in England. Ideas and action points relating to school level education were condensed from the documents and displayed in chart form as described by Miles, Huberman, and Saldaña (2014).

In phase two, semi-structured interviews were conducted during 2013–2014 with 21 long-standing and acknowledged key contributors to the science and/or mathematics education discourse in England, including an engineering educator and a retired civil servant.

Interviewees

As Ball and Junemann (2012) note, it can be difficult to identify membership, connectivity and boundaries of a relatively small policy network, and memberships and influence can change considerably over time. They suggest that the limits are often 'pragmatic and reflect more the limitations of data collection […] than any firm cut-off points in the social relations between actors' (p. 10). Interviewees for this study were selected on the basis that they had some influence on government science or mathematics education policy in the last 30 years. All have influenced the development of the national curriculum and/or worked as government advisors and/or worked for charitable trusts and learned societies and/or sat on the government high-level STEM strategy group.

Some initial interviewees were selected and each participant asked for recommendations or introductions to other potential interviewees. All interviews were conducted by the first author, who has worked in science education in England for several years. The interviewer 'exploited pre-existing links with those in power' (Walford, 2012, p. 112) to gain access to initial participants and then used a reputational snowball by asking interviewees to 'identify others in the field who are particularly influential, important or worth contacting' (Cohen, Manion, & Morrison, 2011, p. 159). The reputational

snowball proved a powerful means of identifying significant contacts in what is a small network. A number of participants were retired and Walford (2012) suggests that access is more likely to such participants and they are more likely to speak freely than those still in power. The interviews were conducted under the auspices of a Ph.D. project but as a professional in the field, they were in a relaxed setting as a conversation between two equals. As all authors are from a science education background, during the course of the research process the positionings and tensions in research ontologies, epistemologies and axiologies were regularly reflected upon as it is acknowledged that these would have an effect on how the research was conducted and analysed, with the aim was at all times to be genuinely open.

The original intention was to interview a similar number of science and mathematics educators. Most of the science educators approached agreed to be interviewed. This was not the case for the mathematics educators. Ultimately 8 mathematics educators, 11 science educators, 1 engineer and a retired civil servant who had worked in both science and mathematics education were interviewed. Care was taken to ensure that there was a balance of disciplinary backgrounds among the science educators, with four physicists, four chemists and three biologists included. Interviewing was continued until it seemed that subsequent interviews, while offering interesting individual perspectives, were not offering anything that was substantively new; that is, data saturation was reached (Rubin & Rubin, 1995). Identifying the key stakeholders is the main limitation of the methods used. The functioning of networks such as this one can be opaque and it can be very difficult to know who the most powerful players are (Ball & Junemann, 2012). The key stakeholders may not all have been identified, interviewing may have stopped too soon and those who declined to be interviewed may have had a unique perspective which is missing from the data. The choice to have a balance of science disciplines represented, the attempt to have a similar number of mathematicians and scientists and the higher refusal rate among mathematicians may all have contributed to skewing the data. Interrogating all interview findings against the analysis of the publically available documents helps to ensure that the findings can be trusted.

Appendix 2 shows the interviewees, their background and limited details of their experience. In order to preserve the anonymity of interviewees, many of whom are well-known names in education, both in England and internationally, further details including age and organisational affiliations are deliberately not included. Initials used in the quotes are pseudonyms. Ethical approval for the research was granted by King's College London and BERA guidelines for ethical research were followed (BERA, 2011).

The interviews

The open-ended interview schedules were different for each participant, being adapted to ask about the projects and activities most relevant to them. However, a common sequence of questions about STEM was included within each interview (Appendix 3), allowing norming of the answers to at least some degree as suggested by Rubin and Rubin (1995, p. 84).

The original study design called for entirely face-to-face interviews, but the contingencies of the data collection meant that some telephone interviews were used. These were due to interviewee preference and covered one ill and two retired interviewees. Sturges and

Hanrahan (2004, p. 108) in comparing telephone and face-to-face data within the same study, concluded that there was no significant difference between the two interview modes and that telephone interviewing can be used successfully in qualitative research. Overall, though, face-to-face interviewing was used wherever possible, as not seeing the participant deprives the interviewer of access to non-verbal communication during the interview.

Nine of the interviewees were previously known to the interviewer and were thus 'acquaintance interviews' (Garton & Copland, 2010). The majority of these acquaintance interviews proceeded in a similar fashion to the non-acquaintance interviews, but in at least one it was difficult to get the interviewee to talk in detail about events and happenings that he believed the interviewer already knew about. This was a small price to pay for the ability to access other interviewees who might not have been available without prior acquaintance as discussed above. Particular care was taken with acquaintances to ensure that they were treated as confidentially as the other interviewees.

Analysis

Interviews were transcribed (intelligent verbatim) and analysed using thematic analysis. The data were coded using a complete coding process, using NVIVO 10 to manage the data. Some deductive (based on theoretical background) codes were used, but the majority were inductive, based on the data and staying close to what participants said, in a grounded approach as described by Charmaz (2006). In total, around 100 codes were generated. Most codes were evident in more than one interview and some were present in most interviews (Braun & Clarke, 2013). From these codes themes were identified which captured patterned response and meaning within the data set. Findings from interviews were checked against each other and discussed with colleagues to ensure reliability and validity.

Finally, the interview data were compared with data from the document analysis and comparisons drawn. Findings came predominantly from the interview data which were interrogated against the document analysis. Particular attention was paid to differences between the document analysis and the interview data and to differences in the interpretations of mathematics educators and science educators. Five themes were identified in the data, with four being predominantly drawn from the interview data although corroborated by the document analysis. The fifth theme, *Changing support for diversity*, came predominantly from the documentary analysis where it featured prominently; in stark contrast the theme was conspicuous by its absence from the interview data.

Findings

Five themes were identified in the data: STEM: a science agenda?; varying perceptions of STEM; changing support for diversity; focus on high-status students and subjects; and access to government. Each is discussed in turn.

STEM: a science agenda?

The original discourse in England was one of SET, following Roberts' (2002) review. Mathematics was deemed to be part of this discourse from the outset, but was not part of the

acronym used both by Roberts and at government level. SET only changed to STEM, explicitly including mathematics, following representations from the mathematics education community.

There was a noticeable disconnect in the data in how this was viewed by the science and mathematics educators. The initial SET agenda was perceived to be strongly dominated by science, to the extent of being a science agenda, as noted by this mathematics educator:

> There was a science S-E-T agenda. *C, mathematics educator*

Mathematics educators were part of the network governing SET initiatives, but felt that mathematics was excluded and invisible, in part as it was not in the acronym SET. For example, one mathematics educator said:

> I remember at every meeting saying maths is supposed to be included in this and where's the maths, I can't see it. *A, mathematics educator*

Strong discussions regarding the place of mathematics were recalled by both science and mathematics educators, for example:

> One of the things I, along with other mathematicians, said maths should be there. And I remember an interaction with Lord Sainsbury and he said well, it is there, everyone knows it's there but it's sort of invisible. And I said, no it's not. If it's invisible you don't see it. *C, mathematics educator*

The feeling of being invisible, of needing to fight to be a seen and acknowledged part of the agenda was mentioned by a number of mathematics educators but none of the science educators, although one did talk about whether STEM was an attempt to change the status of engineering and technology to that of science, which clearly caused some unease:

> There was discussion between the communities about whether [STEM] was about positioning engineering and technology to have the same status [as science] and what that would mean. *P, science educator*

Some mathematics educators even used the language of risk and danger to mathematics education becoming part of STEM, for example:

> There's a real danger that maths is seen as a kind of small subset of science; that's how the science people see it always. *A, mathematics educator*

Vocabulary of risk and danger was not used by any of the science educators. In joining up with STEM, some mathematics educators felt that mathematics became less consequential, just a part of science. When linked with SET mathematics had a useful role, even if it was not as clear as mathematics educators would have liked. Mathematics was seen as its own self, but as part of STEM there was the risk of being subsumed and even subservient. For this mathematics educator, STEM led to a reduction in significance for mathematics:

> SET obviously involves maths and that was quite good but we kept maths separate, but then it all came under STEM and then maths became a bit less important. It's become important again now. We don't have STEM anymore … [STEM] is important, it's just there are other things in maths than science. *C, mathematics educator*

Many of the mathematics educators talked about mathematics having links to far more disciplines than the STEM subjects. They mentioned links with social sciences,

economics, computing, art and the need for basic mathematics and numeracy for the whole population. Several mentioned the risk that joining up with STEM would suggest strong links to science, meaning they could be perceived as ignoring the needs of these other communities, and maybe even the majority of school students as science could be presumed to be for only the most high-achieving students. There was thus the risk that being involved with STEM could look like prioritising the needs of the science community and thus apparently privileging some reasons for studying mathematics ahead of others.

As there is no part of science which does not fit within STEM, there are not the same conflicts for science educators and none of the science educators mentioned any risk or danger in being involved with STEM, nor any sense of being invisible or side-lined.

Giving further weight to the mathematicians' view of STEM being a science agenda to which mathematics had been reluctantly added was the appointment of a science educator to be the National STEM Director. That this was the intention from the outset is clear from the original documentation describing the role, which shows that this person will be directly accountable to the chair of the School Science Board and not the Maths Programme Board (Department for Education and Skills, 2006). The job description also notes that 'The first priority for the STEM Director will be to focus on school science activities and funding streams' (p. 22). This prioritising of science appears to have continued through the formal STEM programme as the later STEM Cohesion Evaluation noted that there was:

> … a continuing lack of understanding and appreciation amongst those working in STEM education of the role of maths in STEM. (NFER, 2011, p. 95)

The evaluation document also noted limited acceptance among 'STEM colleagues' of the importance of mathematics. Thus, the documents substantiate the mathematicians' view that mathematics was added late and remained unaccepted and unappreciated within STEM.

Given all these issues, the question perhaps arises as to why mathematics educators fought to be a part of STEM? There was a large pot of government money available for projects within STEM and to have access to those funds mathematics needed to be a recognised part of the STEM initiatives, as recalled by this mathematics educator:

> If we were having a push on science and engineering [then] to ignore maths was quite stupid. And of course a funding stream came with that so we wanted to be in on that. *A, mathematics educator*

Prior to STEM, there had been money for science education and for mathematics education with the budgets tending to be separate; now they were together with one committee to oversee the spending, which led to fights over how the budget would be spent.

> Funding went to STEM and within the STEM envelope folks fought over whether it would be maths funding or science funding. *J, engineering educator*

It can, therefore, be seen that there were clear differences in how the science educators and the mathematics educators viewed STEM. While mathematics educators could identify some advantages to being in STEM (discussed in 'Access to Government'), they were also aware of a distinct danger-advantage dichotomy which was not present in the same way for science educators.

Varying perceptions of STEM

While there were differences in how science and mathematics educators viewed the initiatives under the STEM banner, there was agreement in their dislike of the term STEM. For example:

> It is an acronym which is, I think, completely fatuous. *D, mathematics educator*

> It's not a term that the ordinary person in the street understands and it can be confusing with stem cells and it has this mixture of Technology and Engineering, probably so that it makes a word rather than any other reason. *U, science educator*

For a number of interviewees there was confusion as to what the T represents at school level, whether Design Technology or Information and Communication Technology (ICT), a combination of the two or neither of those. It was also not clear what the relationship of this uncertain T should be to the other STEM subjects, particularly within education, as summarised here:

> It's the T that has struggled to have any profile at all. And that was partly that no-one was quite sure what it was. *J, engineering educator*

Perhaps partly this animosity for the term resulted from no one being particularly certain about where it had come from. A number of interviewees mentioned it as having come from SET – but aside from the Roberts' (2002) review, no one knew where that term had come from either. Many, like the following interviewee, concluded that it probably did not have its roots in education:

> I'm thinking it came more from the DTI[3]/business side of things because that collection of subjects made sense in the wide world of business when they didn't necessarily in schools. *P, science educator*

There was also an acknowledgement that there was no one clear definition for what STEM is or should be. When we use the term STEM are we sharing an understanding of what it means? One interviewee used a chemical analogy to ask if STEM is a mixture of different disciplines put together as separate entities, or a compound with the disciplines reacted together to form something new. These two conceptions are profoundly different.

Some interviewees suggested that different sectors had interpreted STEM to mean different things, particularly at national level and in schools. For example:

> At National level it means the supply of people, home-grown people with the appropriate skills to service the STEM sector of the economy. At school level it means interdisciplinary work between the subjects of science, technology and mathematics. So it means two completely different things. *B, mathematics educator*

A number of interviewees mentioned the differences between how STEM might be viewed in school and by business. For example:

> [STEM] probably means completely different things to people inside schools and outside schools and if you are inside schools it's the science and the maths that really matter; and if you're outside schools it's the technology and the engineering that matters. *T, science educator*

The majority of those interviewed noted that the reasons why STEM is promoted and was strongly funded by government are economic at heart.

In England, this need for a supply of people has often been articulated by talking about education as a supply pipeline, leading to careers in the world of business. This economic argument for education, while prevalent, does not always sit comfortably with those who are educators and teachers, as this former teacher notes:

> I'm not keen on the pipeline description; I don't think very many people who work in education are very keen on talking about pipelines. *S, science educator*

That there is perhaps tension for educators between economic arguments and what might be seen as the educational ideal is also hinted at by this mathematics educator who had a career in business before moving into education:

> And [STEM] has got an economic *raison d'etre* at the end of the day because you're going to be competing in a fierce job market in a time of austerity and diminished economic prospects. It gives you a better chance. I don't mind that, I've been in business for half my career. *D, mathematics educator*

Needing to specify that 'I don't mind that' suggests that this interviewee has been in contact with plenty of people in education who do mind that – which perhaps supplies another reason why STEM was not particularly popular among educators. It contrasts with teachers' requirements and passion to introduce all children to their subject, including those who are not going to become part of the pipeline.

In *The STEM cohesion programme: Final report*, NFER (2011) found understanding of the term STEM was varied at school level and noted a lack of understanding of STEM as a construct which had a negative impact on lead organisations' ability to engage schools with STEM; a key aim of the STEM cohesion programme.

It can be seen, therefore, that STEM is not always a popular or well-understood term among those involved in education and that there are a variety of conceptions of what it actually means. At national level in England STEM is focused on improving the numbers entering the STEM sector of the economy, often described as a pipeline. This is potentially uncomfortable for those in education, where STEM is often interpreted differently, as some form of interdisciplinary work.

Changing support for diversity

Where the other themes came mainly from the interview data, this one was more marked in particularly the early documentation. Roberts' (2002) review recommended that action was required to improve the number of girls and women in SET but made no specific recommendations for improving girls' take up of science. Roberts did note that girls in particular need to receive accurate and positive careers advice if they are to consider working in SET (or STEM) careers. In the STEM cohesion programme (2006–2010) there was an Action Programme for improving careers advice, but it did not specifically focus on girls. Roberts also recommended investigation into ethnic differences as he noted that there was not much data or awareness of potential issues.

Issues of diversity were picked up in the 2004 *Science and innovation investment framework* (HM Treasury, Department for Education and Skills, Department for Trade and

Industry) which suggested that a step change was required in the number of minority ethnic people and women participating in higher education to ensure a strong supply of scientists, engineers and technologists. It suggested a strategy was in development to support women in SET careers and the report noted that a similar strategy should be developed to address the under-representation of ethnic minorities in SET careers. It was also concerned about girls receiving careers advice which pushes them towards a narrower range of careers than boys, together with a lack of encouragement to continue to study science.

In the 2006 STEM programme report, 1 of the 17 recommended actions relates to diversity with the school science board to explore best practice emerging from an existing programme. Sainsbury's (2007) report made only one mention of diversity, suggesting that better 'awareness' of STEM careers was required and that this could 'help to counter the imbalance in STEM participation by under-represented groups, particularly girls in physics and engineering, and some ethnic minority groups in specific STEM areas' (2007, p. 105). The STEM Cohesion final report (NFER, 2011) made no mention of diversity.

Thus, although the early STEM documentation highlights the need to increase diversity in STEM, this was never prioritised. A rather hopeful suggestion that informing girls and ethnic minorities what careers were available would increase diversity was the final statement from the documentation.

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 these original aims were never operationalised.

Focus on high-status students and subjects

The STEM programme report set out STEM aims as increasing 'the flow of qualified people into the workforce and STEM literacy in the population' (Department for Education and Skills, 2006, p. 4). Quite what was meant by STEM literacy is not clear, and it was not mentioned by any of the interviewees, but its target seems to be all pupils. This motivation contrasts with the aim of providing well-qualified people for industry, which led to an objective of increasing the numbers of school students studying A-levels, the most widely followed pre-university qualification. The preoccupation with A-level numbers was noted by the majority of respondents, for example:

> The headline measure for me was the numbers taking A-level maths and sciences and I continue to think that that's the most important thing. *T, science educator*

However, not all subjects within STEM had equal priority and status as hinted at by this science educator. Mathematics and the sciences were the subjects deemed most significant. Even within science, biology was seen as a lower priority. The variation in status was noted by this interviewee:

> It's curious that the STEM programme meant STEM, except it didn't really mean ICT, didn't really mean biology, didn't really mean engineering … But it absolutely meant physics and maths and to some extent it meant chemistry. *J, engineering educator*

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, as explained here:

> There was perceived to be less of a problem in the biological sciences. Biology was, and is, for example, the most popular A-level in the sciences … And the growth of the popularity of biology was unchecked really for the last 20 years … So it was sort of seen that, well, the real problem is physics and chemistry, which are also very important for the economy so that was the reason. And I think that would still be the reason but biology is actually becoming more and more and more important in economic terms as well as general educational terms so that may change. *T, science educator*

As this science educator explains, the higher status of the physical sciences and mathematics are in part about numbers of students but also about perceived economic importance.

The higher status subjects, science, particularly physical sciences, and mathematics, received the larger share of available funding. The T and E, partly as a result of the confusion surrounding what they were and partly as they did not link obviously to A-levels and therefore to progression, had the lowest status. Government funding for them was non-existent (NFER, 2011, p. 95).

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. The emphasis on numbers also resulted in greater attention being paid to transitions between phases, particularly that transition from compulsory education at the age of 16 and then the school to university transition at 18. Several interviewees talked about each stage being preparation for the next phase of education and the need to give an accurate representation as to what the subject might be about. To improve transition rates post-16, Sainsbury's (2007) report recommended an increase in the number of students taking extra science (so-called triple science) at age 14–16. This is usually only permitted for those students who are anticipated to achieve high grades. Thus, STEM was increasingly focused on high-status students whose potential had already been identified at 14 with concomitant pressure for curricula changes to better suit those students. Aims of improving STEM literacy for all were never clarified or operationalised.

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

Numbers taking physics, mathematics and further mathematics post-16 have begun to rise, and many interviewees pointed to the STEM agenda as helping to raise the profile of the importance of these subjects, and therefore helping to improve up-take. Several mathematicians were reluctant to accept STEM as the reason behind the rise, suggesting a variety of other causes; nonetheless numbers taking physics and particularly mathematics have risen, without an attendant reduction in numbers taking chemistry and biology (Joint Council for Qualifications, 2016).

Access to government

As many interviewees noted, the most critical aspect to achieving any of the aims of the STEM agenda is good teaching and learning. One important way of helping to improve

teaching and learning is through good quality, subject-specific CPD. Many interviewees pointed to initiatives to improve teachers' access to such CPD as being one of the key achievements of STEM. Another was bringing the critical nature of teacher shortages in mathematics and, particularly physical, sciences to the attention of government and in improving the financial incentives for training in these subjects.

This was probably possible due to the ability to have a more direct influence on government policy than previously, as noted by both mathematicians and scientists:

> I do think the STEM agenda had an important voice to government. *C, mathematics educator*

Some of these benefits have continued and have led to ongoing access to decision-making sites of government:

> Charities particularly and Learned Societies, having much better access to civil servants and Government than we ever had before … most of the bodies who've been involved in the STEM agenda in terms of doing things have access to [government ministers] in proper conversation and we have many, many conversations with the civil servants … so I think that's one of the big achievements, that we are able now to have proper discussions and a lot of progress has been made as a result of that. *U, science educator*

This science educator notes that those who have been involved with the STEM agenda have continued to have influence on government discussions and decisions, suggesting that the policy networks are still operational despite a change of government.

While working together may have had its difficulties, it almost certainly did mean that the messages had a higher impact than they would have done separately, as this former civil servant explains:

> In many ways the maths and science communities did, by coming together, by working together, I think did increase the strength and the impact of their lobbying. *K, civil servant*

For all the problems, these were undoubted benefits from the formal government STEM initiatives. STEM succeeded in increasing the status of both science and mathematics education and brought advantages, both financial and through increasing political power, for the organisations most closely associated with the STEM network.

Discussion and conclusions

In England, the STEM discourse has had a significant impact on education policy, schools and, in some cases, classrooms. Although the formal STEM programme has ceased, a political focus on STEM has remained and the legacy of the STEM agenda continues: the importance of STEM subjects was emphasised on more than one occasion by Nicky Morgan, the Secretary of State for Education (July 2014–July 2016), as the following quote illustrates:

> The subjects that keep young people's options open and unlock doors to all sorts of careers are the STEM subjects: science, technology, engineering and maths. *Nicky Morgan, Secretary of State for Education* (2014)

Yet in spite of its prominence, this study shows that there is not a unified idea of what STEM is or should be. Whilst, in England at least, science dominated in national STEM education policies, the individual science disciplines did not gain equally from this

increased emphasis. On the other hand, all the disciplines of science fall within the remit of STEM, whilst other subjects would appear to be classed as STEM only insofar as they support science. This is clearly seen in the documentation and was plainly felt by the majority of mathematics educators. For mathematics educators there was a danger-advantage dichotomy with many using language of danger and risk when discussing being cast as part of STEM. The risk was in being seen as a subset of science, of being subsumed into a wider science-led agenda rather than being identified as a separate subject. A key drawback of being a subset relates to the leverage that subject networks are able to assert within the broader policy network (Ball & Junemann, 2012). For science educators, all parts of their networks relate to STEM, whilst for mathematics educators only parts of the network that overlap with STEM could hold any sway.

The findings also show a disconnect between how STEM was viewed in schools and how it was perceived at a policy level. Education is increasingly seen by governments through an economic lens: as a producer of labour and skills in response to international economic competition (Ball, 2013). In this way, STEM can be seen to be benefiting from economic arguments and, indeed, it retains its prominence through changes of government.

However, for many in education, social justice arguments may be more important than economic arguments. This study shows that the support for diversity found in the documentation – which fit within the New Labour administration's wider support for inclusion and concomitant drives to reduce problems associated with lack of diversity – was not operationalised and there does not seem to have been an attempt to set targets for or to monitor any improvements. The reasons for this lack of monitoring are not entirely clear. Perhaps it is because it was harder to measure progress when the aim was somewhat ephemeral. Perhaps it is because economic arguments regarding the needs of industry are more politically compelling than those of social justice, especially in an era when education exists to serve the economy. It could be argued, however, that simply keeping the issue of diversity in STEM on the political agenda, particularly through a change of government, is a success. The government has, arguably belatedly, co-funded a report by the Institute of Physics on challenging gender stereotyping in schools, which does aim to see an increase in girls choosing physical sciences and engineering courses (Institute of Physics, 2015) and suggests wider actions than simply telling girls about STEM careers. Increasing the ethnic diversity of STEM students continues to receive less attention. Archer and DeWitt (2014) suggest that the science education community has considerable work to do to enable girls to see science as 'for them'.

The key aim in the enactment of the STEM agenda, identified in both the interviews and the documentation, was to increase the numbers of students studying physical sciences and mathematics beyond the age of compulsory schooling. This aim has been realised, at least in part. For example, there has been a significant increase in numbers of students studying mathematics. It is now the most popular A-level in England, studied by almost 11% of the cohort (Joint Council for Qualifications, 2016). There has also been a rise in numbers of students studying physics. It is, of course, difficult to know for certain what caused the rise.

To help increase numbers studying science post-16, the government pushed for an increase in the number of students taking extra science (so-called triple science GCSE) at age 14–16. As this is usually only permitted for those students who are anticipated to

achieve high grades in those subjects, the 'push' essentially served to underline the notion that STEM was primarily focused on 'high achievers' (see also Fairbrother & Dillon, 2009). In turn, STEM also served to channel higher funding to science education: as Goodson (1995) noted, high achievers or high-status students are sought after and funding is channelled to subjects – in this instance science based – in order to attract high-status students.

The broad early aims of STEM in England gradually narrowed to a target of increasing the numbers of students studying physical science and mathematics in post-compulsory education. As it can only ever be a small proportion of students for whom such further study is a realistic option, this target runs the risk that the curriculum is planned with the needs of the few, rather than the majority, in mind. As Millar (2014) has noted, many of the influential scientific bodies in England tend to prioritise science education for this minority group. Although he does not name the organisations to which he refers, it is likely that it includes some who are influential within the STEM policy network. It is difficult, to say the least, to deliver effective education for all based on the needs of an industry that will ultimately employ only a tiny proportion of each cohort, yet this research suggests that the impact of organisations which were involved in the STEM policy network is ongoing and even increasing

Thus, STEM in England did not appear to include a push to widen participation to groups within society who do not often consider careers in science, but only to ensure that a higher proportion of the traditional participants chose to study science. Yet, despite all its problems, STEM is what has framed the recent changes to the school curriculum, particularly in science, and given it its *raison d'être*. This is in spite of the fact that the varied enactments of STEM have not proved helpful in achieving much needed diversity in the STEM workforce. Early STEM ideals of improving the number of women and ethnic minorities choosing STEM careers have not been achieved, or even promoted. Subjects which are seen as lower status, even if they are associated with STEM, such as Design and Technology, and students perceived to be lower achieving, are not catered for within STEM priorities. Contemporary research is moving towards exploring ways to improve science capital as a way of achieving greater equity of participation (Archer, Dawson, DeWitt, Seakins, & Wong, 2015). The way in which STEM policy was enacted was not compatible with ideals of science education for all and social justice and this should be addressed and changes made if STEM continues to be a driver in education policy in the future.

We used the idea of policy networks to guide this study of national policy-making. The concept was most useful when considering how to identify membership, connectivity and boundaries of what is a relatively small policy network. As a result, we used the snowball technique for identifying potential participants which led to contacts which we as authors would not have otherwise considered. As Ball and Junemann (2012) show, these networks are often opaque and it can be difficult to know who has the real power within them or where the most significant connections in the network lie. They argue that 'important aspects of network relations consist of informal social exchanges … that go on behind the scenes' and that it is only possible to access 'glimpses of influence, pale imitations of the real social interactions … that ties people together in relationships and gets things done' (p. 80). As a result this study is able to point to effects of STEM policy and the views of some of those involved in setting it but not to probe who exactly was responsible for specific aspects of enacted policy.

The analysis developed in this paper shows the importance of exploring fully the implications and outcomes of educational policy-making and lobbying and subsequent curricula innovations in order to understand the nature of practice in years to come. STEM was forged in response to threats about a fall in the numbers of adequately trained graduates required to maintain economic competitiveness. However, the lack of clarity regarding its reach and remit has served some subjects well, whilst effectively sidelining others. Some subject networks were able to use STEM to their advantage, other networks experienced it as a double-edged sword. In examining the history of the STEM agenda, it becomes possible to better understand its impact within education.

Notes

1. This paper will focus on STEM as it applies to mathematics and science as will be explained later.
2. These departments were known by a variety of titles over this time period (2001–2011), but for clarity a single department title is used throughout this paper.
3. Department of Trade and Industry.

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Appendix 1

Timeline showing the government STEM documents (top row) and actions

	2002	2004	2006	2007	2008	2010	2011
Government reports on STEM	Get SET for success – Roberts' review	Science and Innovation investment framework	Science and Innovation Investment Framework – next steps; STEM Programme report	The Race to the top – Sainsbury review of science and innovation policies			STEM cohesion programme final evaluation
Other government actions relevant to STEM		Appointment of the government Chief Advisor for mathematics	Appointment of the National STEM director Separate maths and science programme boards combined to form STEM strategy group		End of term for Chief Advisor for Mathematics (not replaced) Start of the STEM cohesion programme	Change of government End of term for National STEM Director (not replaced)	

Appendix 2

Table of interviewees

Among the interviewees were: eight people with national honours for services to education; six authors of government reports on aspects of education; employees or former employees of learned societies and charitable trusts with an interest in science or mathematics education; five professors of education; former employees from the Department for Education and its predecessors; former employees of QCA (the Qualifications and Curriculum Authority which was responsible for school curricula until 2011 when it was abolished); members and former members of the Advisory Committee on Mathematics Education (ACME, an independent committee set up to develop advice on mathematics policy in England) and Science Community Representing Education (SCORE, a similar group for science), both based at the Royal Society; and members of OFQUAL committees (the Office of Qualifications and Examinations Regulation, a non-ministerial government department set up in 2010 which regulates qualifications, examinations and assessments in England).

Interviewee	Background	Interviewed as employee/ former employee of*	Input to national curriculum	Input to government reports or reviews	On a government STEM committee
A	Mathematics	University	✓	✓	x
B	Mathematics	Government body	✓	✓	x
C	Mathematics	Government body	✓	✓	✓
D	Mathematics	Learned society	x	✓	✓
E	Mathematics	Charitable trust	✓	✓	x
F	Mathematics	Charitable trust	✓	✓	x
G	Mathematics	Learned society	x	x	✓
H	Mathematics	Charitable trust	x	x	x
J	Engineering	Learned society	x	✓	✓
K	Civil servant	Government body	✓	✓	✓
L	Science	Learned society	✓	✓	✓
M	Science	Charitable trust	x	✓	✓
N	Science	University	✓	✓	x
P	Science	Charitable trust	x	x	x
Q	Science	University	✓	✓	x
R	Science	Learned society	x	x	x
S	Science	Charitable trust	✓	x	x
T	Science	Government body	✓	✓	✓
U	Science	Learned society	✓	x	✓
V	Science	Government body	✓	✓	x
W	Science	Charitable trust	✓	✓	x

* Note that many of these interviewees have worked for many organisations during the course of their careers. They may have been working for a different organisation when interviewed.

Appendix 3

Interview core questions

- From your perspective, when did the STEM agenda first appear?
- Was this when the term STEM appeared too?
- Where did the STEM agenda come from?
- What was the purpose of the STEM agenda?
- What did the STEM agenda offer to Mathematics education?
- What, in your opinion, did it offer to science education?
- What do you think were the biggest achievements of the STEM agenda?
- From your perspective, what benefits do you think the STEM agenda has offered to schools?
- What has happened to the 'STEM agenda'? How has it evolved over time?
  - Do you think it will last as a concept or term?
- What advantages would there be to mathematics/science departments in schools in working with the other STEM departments?
  - Which departments would it be most advantageous to work with?
  - What might be the benefits to a science department working with the maths department?
  - What might be the issues?
- The science and mathematics education communities do not seem to work together very closely. Is that a fair assessment or is there closer co-operation which is not obvious?
  - From your perspective, do you think there would be any benefit from them doing so?
  - What do you think would help or enable the science and mathematics education communities to work together?
- Mathematics seems to have been spoken about a lot more recently, A-level numbers are up and schools seem more aware of the importance of mathematics. Is this one of the outcomes of the STEM agenda, do you think?
- Can you suggest who else I should talk to?