A qualitative study of the impact and operation of CST Teacher Networks

Short Report

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Introduction

Programme Overview

Connecting STEM Teachers (CST) is a national programme in the UK, hosted by the Royal Academy of Engineering, established with the aim to encourage STEM engagement and aspiration among school students by supporting teachers of STEM subjects through regional training and networking activities. The ambition of the programme is to ensure teachers have the knowledge and confidence to engage a greater number and wider spectrum of students with STEM. The programme aims to raise the profile of engineering in schools and engage more students with engineering by improving their perceptions of engineering through teacher advocacy; promoting the application of engineering in the context of specific STEM subject areas in schools; engaging with schools in areas where the social and economic status is low and increasing the appeal of engineering careers amongst underserved and underrepresented groups of pupils; connecting networks to enhance the provision of STEM learning in schools; and improving student progression to STEM subjects post-16.

Physical resources and hands-on practical training with these student-centred STEM activities are at the centre of the CST network Continuing Professional Development (CPD) activity. The CPD provided through the CST networks aims to facilitate the development of teachers' competence and confidence in using these STEM learning and teaching approaches in their schools. Resources are developed for teachers by teachers in partnership with professional engineers. They are designed to allow students in primary and secondary education aged 9 to 14 to learn by investigating important real-world questions while working in an engineering context. The activities are designed to provide hands-on thematic learning opportunities and bridge several subjects across the science, technology, engineering, arts and mathematics curriculum. The goal of the resources and their hands-on practical focus is to support real world learning which can often be missing in schools' regular curricula. Resource based activities also aim to develop enquiring minds, facilitate teamwork, allow young learners to think laterally and express their thoughts and ideas to support understanding of engineering applications. Through the resources, the programme aims to develop reasoning and career awareness for pupils through practical STEM applications and equip them for a successful transition to post 16 and higher education.

To receive the class set of resources, teachers are expected to attend the network meetings in person and receive hands-on training in the resource. CST Network meetings take place in their geographical areas termly and are organised by teacher coordinators (TCs). TCs experience their own hands-on training on the resource kits from the RAEng prior to their network meetings that are organised accordingly. TC training usually lasts for a full day, involving hands-on training on a new resource kit, speakers from STEM education and other organisations, updates about upcoming events and competitions.

As a result of the Covid-19 pandemic, face to face network meetings stopped and were replaced by online meetings with the introduction of the first lockdown in March 2020. With the ease of restrictions in the beginning of 2022, face-to-face network meetings had been partly resumed, while some networks organised hybrid meetings and some needed to continue online.

About the Evaluation

An evaluation of the operation of the CST Teacher Network was launched in October 2020. The study was developed in response to findings from the longitudinal quantitative study (Kutnick, Good &

Gartland, 2017; 2018) of the impact of the CST programme on teachers. The quantitative study indicated that network meetings predominantly focus on the dissemination of information rather than providing opportunities for reflection and discussion. Findings also revealed that teachers' engagement and take up of CST activity was unevenly distributed between CST networks with some networks seeming to be more effective in engaging teachers than others. The study also found that take-up of CST activity was connected to teachers' length of engagement with the programme. These findings pointed to the importance of exploring best practices in the activities of Teacher Co-ordinators in supporting and developing their networks.

Aims and Research Questions

The objectives of the current phase of evaluation were to explore the operation of the CST networks and teachers' experiences of the CPD offered via these networks:

- to explore the effects of the TC training on TC approaches to: managing and building successful networks, the training they provide during termly meetings, and on promoting the use of wider STEM support;
- to consider the extent of TCs and their networks' collaboration with STEM Learning support networks and other STEM related organisations, FE colleges, HEIs and employers and the impact of the collaborations on their practice;
- to consider patterns of attendance at termly meetings;
- to consider models of communication provided by different networks and the extent TCs use network meetings to disseminate information versus to engage teachers/ exchange ideas;
- to explore factors contributing to engaged networks and factors that contribute to lack of engagement and identify supports, challenges and barriers to developing effective networks;
- to explore whether networks contribute to the development of teachers' enthusiasm and confidence in promoting and leading STEM activity in schools;
- to explore whether networks contribute to general teacher efficacy and STEM/ engineering efficacy;
- to consider the impact of networks on teachers' STEM teaching practices in schools.

Our overarching research questions were:

- What contributes to CST networks effectively supporting teachers in embedding STEM in their schools?
- What undermines CST networks effectively supporting teachers in embedding STEM in their schools?

The impact of the Covid 19 Pandemic on the CST programme at the time of the evaluation

The evaluation started in the midst of the Covid 19 Pandemic. TCs and Teachers only started returning to schools following extended periods of school closure in February 2022. There were extremely high levels of absence in schools as, on returning to the classroom, large numbers of teachers and their students were contracting Covid. Teachers were managing late notice changes to formal assessments alongside significant curricula changes. They were additionally having to provide catch up programmes for students who had fallen behind during school closures. The pandemic has had a significant impact on teachers' opportunities and capacity to develop STEM activities in their schools and to take up CST programme activity and resources; the impact of Covid has been long term and has affected practices in schools for several years. The findings outlined in this report must be considered with the significant impact of Covid 19 on programme activity in mind.

Research Design

The research team first undertook a review of relevant literature with a focus on best practice in CPD and developing networks. The literature review was extensive and considered areas including attributes of effective teacher CPD, the role of Teacher Communities in PD, effectiveness of online PD and communities, the role inclusive and culturally sensitive STEM pedagogies and use of practical, hands-on resources with links to real life applications. Notably much of the professional development literature focused on single subjects (particularly Science).

The literature review informed the focus of the study of the operation of CST networks. This study adopted a qualitative research design informed by constructivism (Charmaz, 2014; Cresswell and Cresswell, 2018). We explored the operation of CST networks through observation of network meetings and by gathering the views and individual experiences of TCs and teachers through interviews. Ethics approval was sought and gained from the University of Suffolk Research Ethics Panel.

Interviews were held with twelve TCs from a range of networks across the UK; these included a mix of rural and urban networks and networks from across England and devolved nations. Following this initial stage, nine networks from across the UK were identified and selected according to a set of selection criteria (varied length of experience with the CST programme, subject specialism, mix of rural and urban networks and men and women TCs) in order to explore the impact of approaches taken by TCs in these different regions. Networks were purposively selected with the support of the project lead, with a focus on identifying effective TC practice alongside ensuring that selected networks represented a full range of networks in terms of geographical location. An exploration of these networks was undertaken through observations and interviews with two or three teachers from each of the selected networks. In total twenty-four teachers were interviewed. Teachers/ network attendees were identified for participation in interviews by TCs and so generally represented more committed and engaged members who had been involved with the programme for over two years.

The research team attended one to two face to face or online meetings run by TCs in each of nine selected networks. Interviews were subsequently held with teachers. Interviews with TCs and teachers all took place online via Teams or Zoom. A loosely structured approach was taken to all interview/conversations with the aim to enable participants to relate and explore their own understandings, knowledge and experiences as freely as possible (Hollway & Jefferson, 2013; Kvale, 1996). Interviews were transcribed verbatim. Interview transcripts and notes from observations were analysed thematically (Braun and Clarke, 2013).

Undertaking the research during the pandemic presented significant challenges for the research team. Network meetings were repeatedly cancelled, at times at very short notice. Interviews with teachers had to be significantly delayed due to a combination of staff illness and the very high demands placed on teachers' time by changes to formal assessments of students' work. Interviews with teachers were reorganized several times due to illness and competing demands. As a result of these delays interviews with teachers were not completed until August 2022, which impacted on the planned evaluation schedule and completion of this report.

Literature Review

The School Landscape

Decline in interest and take up of Science, Technology, Engineering and Mathematics (STEM) subjects amongst secondary school aged pupils has been raised as a major concern internationally, with students from lower socio- economic groups, girls, and some black and minority ethnic groups particularly underrepresented (Engineering UK, 2020; Smith and White, 2011; Morley, 2012).

The UK school landscape presents significant challenges to the CST programme. Research points to schools in the UK being ineffective in motivating young people in STEM subjects and preparing pupils for global challenges that need to be met (Lucas & Spencer, 2020; Osborne & Dillon, 2008). While there is broad consensus on the need for change in STEM education, a pressing question for teachers is how changes in their classroom practice can be effectively organised to cater for mixed groups of students, including students with special needs and disabilities, from disadvantaged group and students experiencing marginalization (OECD, 2015; Kutnick, Gartland & Good, 2022). There is a crisis in teacher recruitment and retention, with STEM subjects notably affected, leading to an increase in non-specialists teaching STEM subjects (Engineering UK, 2020; Martin, 2022). Curricula reforms introduced by the Conservative government (2015-2019), with the intention of raising educational standards, have been found to have had unintended consequences in schools, including increasing inequalities in students' performance at GCSE, and increasing issues with students' mental health (Engineering UK, 2020).

There are additional challenges in the UK school landscape due to COVID-19 pandemic which is likely to have lasting repercussions. There has been a reported negative impact on pupils' levels of attainment, particularly those from disadvantaged backgrounds; this has been found to be most evident amongst primary school children and pupils in KS3 (EEF, 2022). Pupils' performance in Maths and reading following the pandemic has been lower than in previous cohorts. There are also increased concerns about pupils' mental health and wellbeing (EEF, 2022). These concerns are driving priorities in schools and there has been a long-term impact on the provision of extra-curricular activities such as STEM clubs.

Embedding STEM in schools

STEM subjects (science, technology, engineering, and mathematics) have been promoted by UK governments over the last two decades. However, there is a lack of agreement on the definition of STEM, and there are concerns about science being too dominant and engineering being neglected (Wong, Dillon & King, 2016). Curricular integration of STEM subjects is a focus of many initiatives (National Research Council, 2014; Sanders, 2009), but it is challenging for teachers and at odds with secondary school curricula in England that divide subjects into isolated disciplines. There are variations in approaches in devolved nations with a new curriculum framework in Wales that is attempting to promote a more integrated approach (Curriculum and Assessment Act (Wales), 2021) and Engineering is better represented in the curriculum in Scotland (Engineering, UK, 2020).

Multi-disciplinary and interdisciplinary approaches have been found to make STEM subject disciplines more relevant to school students (Reiss, 2020; Owens et al., 2017, Sadler & Zeidler, 2003). However, there are concerns that integrated STEM education can focus heavily on science and neglect other areas, such as Maths. STEAM (STEM + Arts) is another approach that aims to bring students' creativity and imagination to STEM subjects (Linder et. al, 2016). However, there are complexities in the implementation of STEAM in the classroom including teacher training and added workload (Becker & Park, 2011; Walker, 2017; Zhang, Orrill, & Campbell, 2015).

Student-centred approaches such as problem-based learning (PBL), project-based learning (PjBL) and Inquiry-based learning are often seen as effective strategies in promoting engagement with STEM in schools (Marshall & Alston, 2014; Chen et al., 2014). PBL and PjBL are STEM pedagogical approaches that involve students actively working on a real-world problem. These approaches have potential for developing Engineering Habits of Mind (EHoM) (Lucas & Hanson, 2016) and allow students to construct and compare their own knowledge (Baden & Major, 2004). Lucas and Hanson (2016) suggest the Engineering Design Process (EDP) as a potential signature pedagogy for engineering education. The EDP is considered an effective interdisciplinary approach to learning (Moore et al., 2014) that is flexible and student-centred, allowing integration with other subjects and hands-on problem solving. However, the implementation of fully interdisciplinary approaches is challenging under current curricular models and teaching strategies. Time limitations constrain approaches teachers can use in classrooms and existing didactic learning and teaching can make it difficult for students to adapt to student centred approaches (Baines, Baltchford & Kutnick, 2017).

Inclusive approaches in STEM education

The attitudes of young people towards STEM subjects and careers are widely acknowledged to be a major challenge in promoting inclusivity in the field (Archer et al., 2010; Dawson, 2014, Calabrese-Barton et al., 2013). Research has shown that these attitudes are shaped by a student's identity and perspectives from a young age. To effectively engage students who are underrepresented in STEM, a student-centred approach is crucial (Schlegel et.al.,2019). This approach not only promotes self-efficacy and a positive science identity, but it also allows students to see themselves as possible future STEM professionals.

To achieve this, it is important to focus on making long-term changes to core pedagogical practices in schools (Godec et. al, 2017). This requires a reflective framework that broadens what counts as STEM-related experiences, allowing young people to identify with STEM and connect their own experiences to the field. STEM clubs have been found to be a valuable resource for this approach, as they provide a supportive and collaborative setting for play and learning, free from the constraints of the curriculum and timetable. When STEM activities are presented as creative and open-ended, with room for imagination and exploration, this can lead to more equitable engagement and a greater appreciation of STEM (Rushton & King, 2020).

Promoting awareness of careers in STEM

The lack of knowledge of engineering careers in the UK is a long-standing issue that is partly due to the limited provision of Careers Education, Information, Advice, and Guidance (CEIAG) in schools. While in Scotland, a government funded CEIAG service (Skills Development Scotland) is available, but in other parts of the UK, schools are solely responsible for providing impartial careers guidance to students, often without additional funding. This has resulted in widespread criticisms, especially given the marketized school system and competition for students.

Inconsistencies in provision of CEIAG have led to significant inequalities, with students from disadvantaged backgrounds being less likely to receive CEIAG (Moote & Archer, 2018). Despite recent efforts to improve provision, such as through the introduction of the "Baker Clause" and requirement for schools to meet the Gatsby benchmarks, concerns remain over lack of funding and patchy provision (Hubble, 2022). To effectively promote STEM careers, schools need to provide students with a comprehensive understanding of STEM, including its importance in everyday life and the transferability of STEM skills (STEM Careers Toolkits, 2020). By embedding careers education in STEM lessons, students can learn about STEM careers, build self-efficacy, and form subject and career interests that align with their aspirations (Reiss & Mujtaba, 2017).

Teacher Professional Development

Teacher CPD appears to offer an obvious and cost effective (The Royal Society, 2022) way forward in supporting teachers to promote engagement with STEM. However, developing effective CPD provision is not simple. An issue widely identified is that there is often a mismatch between the ambitions of CPD and the requirements imposed on teachers by external measures of students' learning. The impacts of policy environments focused on 'standardised examination results and restricted notions of teacher accountability' (Avalos, 2011: 18) are also noted. National assessments of students' learning focus on 'mastery of facts' whereas CPD often aims to develop conceptual understanding and promote engagement, for example with scientific practices (Wilson, 2013: 17). Additionally, there are few drivers to promote teacher engagement with CPD. Opfer & Pedder found that in the UK, CPD is largely 'left to individuals and their own wish to develop' (2010b: 462). Research into CPD in the UK has found that provision is limited and often reliant on transmissive approaches (Opfer & Pedder, 2010b; Cordinley at al., 2015b).

Attributes of Effective CPD

Against the backdrop of the challenges identified, various attributes of effective approaches to teacher CPD have been proposed by researchers. Desimone's (2009) influential work on CPD effectiveness identifies five key features: duration, content focus, coherence, collective participation, and active learning. Cordingley et al's umbrella review of CPD (2015: 4) highlights the need for prolonged, sustained CPD that features 'multiple, iterative activities following the initial input with relevant content to participants, the creation of a shared sense of purpose, and opportunities for reflection and collaboration. Providing teachers with specific teaching strategies and giving the time to try out and reflect on new approaches (Wilson, 2013) and experimentation (Borko et al, 2010) are also found to be important. Active learning during CPD (Whitworth & Chui, 2015) is widely held to be vital as the experience of successfully implementing new approaches can change teachers' beliefs and attitudes (Guskey, 2002). Researchers have argued that an effective model of CPD leads to increases in teacher self-efficacy (Whitworth and Chui,2015). For example, Kelley et al. (2020:11) found teacher self-efficacy was developed 'through the processes of modelling, collaborative reflection, and implementation of integrated STEM lessons'. Increased self-efficacy is widely acknowledged to lead to higher levels of teacher persistence, reduced work related anxiety and improved outcomes for students (Wilson, 2013:19, Takahashi, 2011; Yi-Hwa Liou et al., 2017). Teachers' self- efficacy has been used to measure the impact of STEM CPD programmes (e.g., Hardre et al., 2013; Nadelson et al., 2013; Kutnick et al., 2022).

Several researchers, however, point out that a focus on the design features of effective CPD neglects explanations of causality (Opfer and Pedder, 2010; Evans, 2014; Kennedy, 2016). Opfer and Pedder (2010a) suggest there is a need for a deeper focus on 'supporting improvements in the learning and learning conditions of leaders, teachers, and pupils' (429). Indeed, CPD has been noted to contribute to preventing teacher attrition (Whitworth & Chui, 2015) which is particularly vital in STEM subject disciplines. Various researchers also highlight a need to work with teachers as professionals and to actively engage them in thinking about their practice on an intellectual level (El-Dehaidy & Mansour, 2015; Nelson et al, 2015; Cordingley et al., 2015; Kennedy, 2016; McChesney & Aldridge, 2019; Liou et al.,2020).

The role of facilitators of PD has also been highlighted in the literature. Cordingley et al. identify external input from an expert leader who can model practice, provide coaching, and observe teaching as a feature of successful PD (Cordingley et al, 2015), however for this to happen experts should treat teachers as 'peers and co-learners'(2015b:6). Nelson et al (2016) suggest a need for both internal and

external expertise to support professional development, noting the importance of bringing together knowledge from both research and practice. Kennedy (2016) and Mc Chesney & Aldridge (2019) note that effective CPD programs are offered by people who have extensive knowledge and experience of working with teachers while El-Dehaidy & Mansour (2015) suggest that content for CPD should be developed in partnership with teachers and providers not imposed by external bodies.

Role of Teacher Communities in Teacher CPD

The CPD literature widely points to the vital role of teachers' collaboration with their peers (e.g. Desimone, 2009; Avlos, 2011; Whitworth & Chui, 2015; Cordingley, 2015). Research notes the benefits of teachers working with others *within* and *between* schools, and the crucial role of social interaction for improvement at both individual and organisational levels is widely acknowledged (e.g. Liou et al, 2020). Collaboration has been identified as an important way to support teacher professional development through access to and exchange of valuable resources (Schleicher, 2012; Liou et al, 2020). Communities of educators 'can facilitate sharing of best practices via the rapid flow and propagation of innovation' (Khalil et al. 2016: 13) and increase teachers' pedagogic content knowledge (PCK) while changing their practices to more constructivist and inquiry-based approaches (Dogan et al, 2015). Indeed, Brown & Flood observe that ''capital' resource networks' are now seen as a more effective mechanism for professional improvement than 'top-down mechanisms' (2020: 1).

Top-down, externally sponsored networks have been found to work against the development of effective teacher communities (De Lima, 2010; Vangrieken et al. 2017). Vangrieken et al. highlight the importance of the 'collective desire' of network members 'to learn from each other's varied expertise' (2017: 53); indeed, utilising network teachers' expertise is widely viewed to be vital to effective teacher networks and there is a need to allocate time for this activity (Baker-Doyle & Yoon, 2011; Hardre et al, 2013; Hofman & Dijkstra, 2010). According to Vengrieken et al's review, successful outcomes of Teacher Communities 'in terms of changing participants' views and teaching practice, as well as their continued work as a teacher community' (2017: 54) were influenced heavily by interactions between teachers and between teachers and facilitators.

The core group of a teacher network has been found to be important to embedding knowledge and the longevity of the group. However, an active, inward looking core group can also work against innovation and can even be responsible for embedding outdated/ information that lacks value (Hanraets et al, 2011; Khalil et al., 2016). De Lima (2010: 10) warns against 'sparse and highly centralised networks' that operate in 'specific single-purpose domains', suggesting that these very 'goal-directed' networks can prevent the effective development of communities of practice. De Lima also notes that as networks become more successful and expand there is a tendency for them to lose their 'informality' and 'flexibility' and become more formal and rigid (De Lima, 2010: 9-10).

Research also suggests that both weak ties between members that provide access to new knowledge and strong ties that can extend and embed knowledge and learning in practice have value (Hanraets et al.,2011). The quality of ties with other network members may be more important for early career teachers, who particularly benefit from supportive, trusting relationships (Baker- Doyle et al. 2020:2). There is a general assumption that members of networks share knowledge gained within their own organisations. However, De Lima (2010) questions the notion that individuals act as 'bridges' between the network and their own organisations and observes that this may well not be the case as it depends on the actors' centrality in their own institutions.

Additionally, location and participation are suggested to play important roles for developing effective teacher communities. Hoffman & Dijkstra (2010) suggest a maximum number of fifteen participants and warn against higher numbers. They caution against networks that are too geographically spread out due to issues with travel time and costs but also suggest there may be tensions caused by schools being too close together and in competition with each other for local students.

In addition to network structure and location, the substance and dynamics of the networks are highlighted as significant. Research overwhelmingly supports the need for teacher communities to have a shared focus, shared objectives and shared values and beliefs (De Lima, 2010; Hoffman & Dijkstra, 2010; Vangrieken et al, 2017; Liou et al., 2020), with opportunities for sharing practice, professional reflection, collaborative learning and collective responsibility (De Lima, 2010; Hoffman & Dijkstra, 2010; Vangrieken et al., 2017; Liou et al, 2020).

Effectively developing trusting relationships between teachers in networks is widely acknowledged to be vital to successful outcomes (Hoffman & Dijkstra, 2010; Khalil et al., 2016; Vangrieken et al., 2017; Liou et al, 2020) as this creates a sense of safety to share experiences, to foster collaboration, commitment and motivation, to support the sharing of information and to build collective teacher efficacy (Hoffman & Dijkstra, 2010; Khalil et al., 2016; Vangrieken et al, 2017; Baker-Doyle et al., 2020; Liou et al, 2020). Establishing 'a culture of trust' in teacher networks, however, can take considerable time and commitment (Vangrieken et al, 2017: 54). Baker-Doyle et al. (2020) notes the vital importance of trust in teacher networks for new teachers, suggesting that for early career teachers 'building trust in the teacher network may be more important than or a precursor to fostering agency (in the form of self-efficacy)' (Baker-Doyle et al., 2020: 4).

School leadership teams appear to be vital in establishing the conditions for successful outcomes for teacher communities (Varga-Atkins et al., 2010; Vangrieken et al., 2017; Hoffman & Dijkstra, 2010). However, this requires leaders and facilitators to carefully negotiate and support the building of relationships and trust (Hanraets et al, 2011) and to understand the needs of participants (Hanraets et al, 2011: 97). Varga-Atkins et al (2010) found that 'positive school culture and intra-school collaboration' were of equal importance to the effectiveness of CPD (2010: 265) though De Lima (2010) notes tensions for school leaders in relation to supporting collaboration with other schools.

The importance of the sustained efforts of moderators, facilitators and leadership figures are also widely noted (Valerao, 2013; Vangrieken et al., 2017; Lantz-Andersson, 2018). Lantz-Andersson et al. identified that 'even the most informally developed communities … depend on the sustained efforts of moderators' (Lantz-Andersson, 2018: 313).

Online Teacher Professional Development and Networks

While gaining significant attention recently, online professional development is not a recent phenomenon as there is a considerable body of existing literature. Previous studies suggest that online CPD and learning communities can provide opportunities for informal exchange of best practices and support peer learning (Avalos, 2011) while improving authentic and personalised learning (Duncan-Howell, 2010). One of the most important benefits of such online networks and CPD noted is the opportunity presented for critical inquiry with peers at a distance (Holmes, 2013; Lytle& Cochran-Smith, 1999; Vescio et,al, 1999). Indeed, by making use of online tools, teachers can overcome geographical barriers and connect with their peers from different schools, regions and countries (Leask, & Younie, 2001; Stoll et. al, 2007; Hramiak, 2010;-Kilpatrick & Fraser, 2019). Several studies made direct comparison of online vs face to face CPD with mixed results. For example, Fisher et al. (2010), and Fishman et al. (2013), found no significant difference between online and face to face CPD approaches, while a study of high school biology teachers (Goldenberg et.al, 2014) reported

that following online CPD teachers scored higher on content knowledge and pedagogical knowledge in comparison to those attending CPD in person. In a more recent study Binmohsen & Abrahams (2022) found online CPD more effective in terms of developing conceptual understanding and providing higher overall satisfaction to teachers.

Despite potential advantages, online CPD programmes have important limitations. Specifically, social presence can be essential for building trust and confidence and for fostering the development of community (Vangrieken, et.al, 2017; Liou et.al, 2020; Baker-Doyle et.al, 2020) which may be difficult to achieve in an online format (De Lima, 2010; Hanraets et.al, 2011). There can also be challenges in promoting participation in online based communities with some people choosing to be passive consumers of information whilst others may dominate (Lantz-Andersson et.al, 2018). The literature identifies the importance of including time, space and activities specifically dedicated to social interaction and building social presence (Kreijns et.al, 2002; Shih & Swan, 2017) in professional development programmes, but with online modality, there may be limited feasibility and opportunity for such meaningful interactions.

Key points from the literature

The literature highlights a number of challenges and approaches that are highly relevant to the CST programme. The lack of clarity about STEM, dominance of Science in STEM and difficulties regarding integration of STEM within existing curricular are all challenges for the programme. The programme champions student centred, interdisciplinary approaches with a focus on real world problems but embedding this activity is fraught with difficulty in schools where teachers' focus is necessarily on the often incompatible requirements imposed by external measures of student learning.

Relevant attributes of effective CPD have been identified in the literature, including the need for CPD to be prolonged, active, relevant to participants and collaborative, with opportunities for reflection and experimentation. Research indicates that such effective CPD can lead to increases in teacher self-efficacy. Researchers also argue for a focus on teachers' learning with some suggesting CPD should be co-developed with teachers. The important role of CPD facilitators is noted with suggestions that facilitators should support collaboration and provide coaching and support for teachers. Research into online CPD and teacher networks indicates online approaches can effectively support teachers' learning and enable participation by overcoming geographical barriers. However, online activities have been found to be far less successful in supporting the development of social interaction, teacher communities and collaborations.

The vital importance of collaboration is central to discussions of effective CPD and important lessons can be learnt from the literature about how to support collaborative approaches in CST networks. Benefits are seen to derive from teachers working with others from both within their own schools and from other schools. Networks where teachers actively share knowledge have been found to be more effective in supporting professional development than top-down approaches to CPD. Shared objectives and values, opportunities for sharing practice, opportunities for reflection, a sense of collective responsibility and the development of trusting relationships between teachers in networks are all significant. The organization of networks and centrality of participants also affects the extent to which knowledge is shared. The size and geographical spread of networks are other important considerations. Research questions assumptions that teachers act as bridges, sharing knowledge and experiences from CPD with their own organisations; the positioning of teachers within their own organisations is significant to effective dissemination within schools. The involvement of school leadership teams is also seen to be vital in enabling effective teacher communities.

Findings

The Teacher Coordinators

TC role and project aims

TCs described themselves as being committed STEM educators, though often focused predominantly in their own subject discipline (notably D&T or Science). They saw their TC role as being to promote the STEM agenda; to bring experts in STEM together to provide a local hub to support teachers; to raise awareness in schools of real-world applications; raise awareness of the relevance of STEM to future careers; and to encourage participation in STEM of underrepresented groups including lower economic groups and girls.

TCs identified key tasks to be the dissemination of RAEng resources and guiding teachers in the use of resources; distribution of information about RAEng led education activities; and distribution of information about STEM activities lead by other organisations. TCs viewed their role to be facilitative as teachers in schools have limited time to identify valuable STEM resources and opportunities.

A point of difference between TCs' views of their role was the extent to which they prioritised communication and collaboration with their network teachers and schools. A focus on communication and collaboration within networks was notably found in the accounts of some women TCs. Peer to peer sharing and collaboration was identified as important by a small number of these TCs who talked specifically about wanting to facilitate collaboration between teachers within their network. However, being responsive to network teachers was time consuming and the time commitment required exceeded time allocated for the paid TC role. There was concern amongst some TCs that if networks became too large, the more bespoke support they currently provided would no longer be possible.

TC training

TCs appreciated the wide-ranging training they received and discussed the training provided by external organisations. The training from STEM Learning was viewed as beneficial for newer TCs though some more experienced TCs felt it repeated what they already knew. TCs valued the input from other STEM organisations for the provision of useful contacts and information. Some viewed the input from TeachFirst to be valuable though questions were raised about the relevance of the focus on teaching strategies to the role of TC.

The training provided with resources and the opportunities for interaction and reflection during training sessions were highly valued and viewed to be a model for TCs' own network meetings. However, TCs who had worked with the programme for many years critiqued the fact that expansion had led to a much more didactic and information heavy approach to training.

Opportunities for sharing TC practice

Training events provided valued opportunities to develop links with other TCs and share ideas. Online training (during the pandemic) did not effectively replicate these opportunities. A TC WhatsApp group was seen as largely effective in replicating the valuable informal networking opportunities provided during face to face sessions. TCs discussed different levels of participation with the WhatsApp group with some more dominant voices, but TCs were able to use the App in a way that suited their individual needs. For newer TCs, the WhatsApp group was viewed to be valuable in providing quick feedback, though one participant described feeling daunted about posting in such a large group. The Teams site where information and resources are posted was widely considered useful but there was some concern over the volume of communication TCs were receiving via these different platforms.

TCs also discussed working closely with a small number of TCs they knew better, as well as some more experienced TCs providing support/ mentoring for newer TCs.

Developing and maintaining networks

Building networks

TCs discussed how their involvement with STEM networks such as STEM Learning had supported them in developing their networks. Working collaboratively with STEM Learning organisations had helped extend the reach of networks and increase numbers of attendees at meetings.

In some cases, teachers attending meetings were already extensively involved with STEM organisations and were experienced STEM educators themselves. Connections with other STEM organisations at times shaped relationships between teachers within CST networks with a core group of teachers often having pre-established, long term and close working relationships e.g. via a subject specific organisation.

TCs discussed the role of other organisations in supporting the development of their networks, notably Multi Academy Trusts (MATs). However, MATs were sometimes seen to be too inward looking and difficult to engage. Competition between schools was also noted as an issue. TCs' roles in Initial Teacher Training (ITT) supported building networks and a number of teachers interviewed described having been trained by TCs. Social media was also used by TCs to build networks.

A challenge frequently noted was staff turnover and teachers leaving schools, which often resulted in loss of contact with school. Other challenges noted included that CPD for teachers was not well supported in schools, and that there is a lack of trust and 'fatigue' in secondary schools with multiple offers from different providers and short-term programmes.

Who attends

TCs described network meetings as attracting between 10-25 teachers with most having a core group of 8-10. Usually, one teacher attends from each school. Some networks appeared to attract more regular and consistent attendance than others.

Moving network meetings online during the pandemic had increased attendance and extended the geographical reach of networks. However, teachers appeared more likely to drop out of meetings. New groups of teachers attending network meetings each time presented challenges for TCs, including changing the dynamic of meetings and a need for repeated introductions to the CST programme.

More than one teacher from each school attending meetings was viewed to be beneficial and ensure schools maintain engagement; some schools ensured several teachers attended network meetings. However, limiting entitlement to one set of resources per school appeared to act as a disincentive for more than one teacher attending from each school.

A range of teachers attend network meetings in terms of position in school and experience, including senior and middle managers, teachers with responsibility for STEM and/or STEM clubs, mainstream teachers and science technicians.

TCs noted the benefits of Secondary School Middle Management (Heads of Department) involvement as they can delegate to other teachers in their schools, ensuring consistent attendance. Middle managers are well positioned to embed project activity in schools. TCs also noted the benefits of Senior Leadership Team (SLT) engagement with networks as they can designate responsibilities and set an agenda in schools ensuring resources are valued and utilized. TCs widely commented on the enthusiasm amongst primary school teachers for the CST network with Senior with Middle managers

often attending. There were also instances of SLT from MATs attending network meetings who were able to promote engagement amongst teachers from across several schools.

TCs, accounts however pointed to a preponderance of mainstream teachers attending from secondary schools and 'junior' teachers with responsibility for leading STEM clubs. TCs also noted relatively high numbers of early career teachers attending network meetings. Trainee teachers were also present at some meetings (particularly where TCs were involved in teacher training).

TCs and teachers often noted that networks were dominated by Science or D&T teachers. This usually linked to TCs own subject specialism and also where STEM was located in secondary schools; STEM in schools often appeared to be seen as synonymous with Science. Engagement of Maths teachers in networks was more limited though D&T teachers were sometimes also teaching Maths and Computing. Teachers noted that the preponderance of teachers from one subject discipline attending meetings led to teachers from other disciplines leaving CST networks.

Motivation for attendance

Teachers were generally seen by TCs to be motivated to attend network meetings by their interest in STEM and commitment to students. TCs and teachers alike viewed the high-quality free resources as well as up to date information about opportunities in STEM to be drivers for attendance. The free resources were noted as particularly relevant for primary teachers and secondary teachers in Wales due to the new Welsh curriculum, as in both instances STEM could be taught in an integrated way. The resources were also widely valued for STEM clubs. Teachers involved in careers education also cited their interest in careers education as a motivation for attending meetings. The reputation of TCs and positive experience during meeting (including food and drinks) were seen as important motivators. TCs and teachers from more collaborative orientated networks also discussed the importance of opportunities for networking and of feeling valued and included.

The importance of location

the location of network meeting and proximity for schools was widely noted as significant. Distance was a key obstacle for face-to-face attendance, particularly for teachers from rural areas though geographically isolated schools were identified as being in urgent need of support. Online meetings had enabled more teachers to attend but teachers and TCs expressed a preference for a return to face-to-face meetings. TCs discussed different plans to support attendance that included a move to a mix of face to face and online meetings, and hybrid sessions where teachers could choose to join online or face to face. TCs' and teachers' accounts indicated differences in teachers' attitudes to collaboration between the different countries in the UK with more enthusiasm and drivers for collaboration in the devolved nations (notably driven by the Welsh curriculum).

The contribution of STEM learning and other organisations

STEM Learning

TCs generally described having close working relationships with STEM learning regional partnerships. Working with STEM learning extended the reach of networks and increased numbers of teachers attending network meetings. The relationship was also viewed to be beneficial for STEM learning and STEM ambassador hubs, providing opportunities for them to reach new schools and to access training for ambassadors.

STEM learning regional partnerships and STEM ambassadors widely contributed to network meetings. STEM ambassadors with expertise linked to resource packs were highly valued and provided opportunities for teachers to meet and discuss potential ways of working with ambassadors and to think through approaches to integrating ambassadors into lessons. Teachers' increased familiarity

with using online platforms appeared to be supporting the use of STEM ambassadors in schools and there was enthusiasm for ambassadors amongst teachers who viewed them as being able to bring new perspectives to lessons and raise awareness of real-world applications for STEM.

TCs were also bidding for Enthuse funding to support collaboration within their networks, though there were concerns that this could be exclusive of some network members.

Some concerns were raised by TCs that ambassadors took up too much time in network meetings. Issues were noted in devolved nations over access to STEM learning. One TC also expressed concerns that the identity of the CST network was being subsumed within larger STEM learning organisations.

STEM and other organisations

TCs also discussed working with a range of other local and national STEM providers (such as the Ogden Trust, Vex Robotics, Crest) and encouraging teachers to take up available opportunities. TCs provided examples of how building these links could be transformative for schools.

Universities were useful allies for TCs who gave examples of working with local University Engineering Departments, linking with Engineering outreach activity and working with Social Responsibility Teams to hold collaborative events and support network activity. Local engineering companies had also offered opportunities for visits and provided space for network meetings as well as providing apprenticeship opportunities etc. for students.

Other national organisations such as the Regional Association of Secondary Heads were drawn on by TCs, for example to promote meetings to Head Teachers. The importance of SLT engagement to promoting network attendance and developing a STEM agenda in schools was widely acknowledged by TCs. There were also instances of networks acting as influencers (e.g. with a regional government organisation).

Networks were acting as STEM information hubs, connecting teachers and raising awareness of a wide range of available opportunities.

Network meetings: Online and Face to Face

During the period of the evaluation, a number of network meetings were still taking place online due to the pandemic. While face to face meetings provide a platform for an effective learning and sharing environment for teachers, these benefits did not always translate as well to online sessions. Despite these drawbacks, online has its own benefits and strengths.

Opportunities for discussion and conversation

Teachers accounts pointed to the value of opportunities for conversations with other teachers and with the TC. They appreciated the opportunity network meetings provided to find out about tried and tested STEM resources and activities.

Some collaborative orientated networks continued with a collaborative approach during online meetings, and teachers described having opportunities for discussion. However, in most networks teachers described the experience of online meetings as more passive and less personal than face to face meetings. Shorter online meetings provided fewer opportunities for conversations that support and develop understanding. TCs and teachers were generally in favour of a mix of face to face and online meetings in the future. Online meetings were seen to be more flexible, providing opportunities for meetings to be offered more than once, and were notably valued in rural communities where travelling to face to face meetings is challenging.

Strategies to improve the online experience

Moving meetings online presented challenges for TCs and teachers as physically engaging with resources had always been at the centre of CST network meetings**.** The RAEng responded to this challenge by sending out sample packs of resources to teachers before online meetings, which was found to significantly improve teachers' engagement with and understanding of resources.

TCs reported using a range of strategies and online tools to improve the effectiveness of online meetings further. This included using different online platforms, using chat functions, breakout rooms, shared online space and Padlet. In more collaborative orientated networks TCs described using the expertise of network members to support other teachers, for example during breakout sessions and by providing information via the chat function.

CPD focus on the resource

Teachers valued the CPD with new resources and opportunities for hands on interaction with the resources. This prepared teachers to use resources with their students and enabled them to work through potential problems. This was seen to be especially valuable when resources focused on an area unfamiliar to teachers. Teachers described finding online CPD sessions more difficult to access when they were only able to watch instructions with the resource.

Positioning teachers as students

An effective feature of CPD with resources identified by TCs and teachers was that teachers were positioned as students and experienced hands on working with the resources themselves. This provided them with a better understanding of the practicalities and challenges their students may face/experience. The initial move to online meetings had prevented this opportunity for hands on interaction with resources, which was viewed as challenging by both TCs and teachers. The move to send out sample packs of resources helped TCs maintain this focus on positioning teachers as students, though not all teachers engaged practically with resources during online meetings.

Teachers as 'bridges': sharing within schools

Sharing within schools

Teachers' accounts indicated there are many challenges and barriers to sharing CST resources and information from meetings within their own schools. The repercussions of Covid, staff illness, alongside challenging new curricula and OFSTED demands in English schools were all cited as obstacles to developing STEM activity. A lack of time and opportunity to work with colleagues and share ideas was also identified as a key issue.

TC and teachers' accounts again highlighted the benefits of SLT engagement. In primary schools, members of the SLT often appeared to be directly involved with project activity; one teacher interviewed was herself a member of the SLT and had attended meetings herself alongside other key staff. Teachers in primary schools also discussed the benefits of being in a small school where teachers work closely together and communication with key members of staff in the school staffroom is relatively easy.

In larger secondary schools, sharing across schools generally appeared more problematic. SLT in secondary schools were often described as supportive but this support often did not manifest in direct action. While some SLTs were actively engaging with ways to promote a STEM agenda, such as through the appointment of a STEM co-ordinator and consciously building STEM activity into the curriculum or systematically through extra-curricular activity, other SLT were focused on individual subjects and did not see the value of a broader STEM approach.

Teachers' accounts highlighted simple steps that could be taken to embed STEM activity e.g. one teacher discussed how time for HoDs in different subject areas to work together to discuss how to integrate STEM in their curricula would be a significant help. STEM was often located in separate D&T or Science departments (sometimes in both at the same time but no co-ordination between the two). Different schools hosting CST network meetings was found to be effective in raising the profile of STEM activity within schools.

Accounts of teachers in Northern Ireland and Wales suggested a generally more positive environment in schools for developing STEM activity, with the new curricula in Wales particularly supporting cross-curricular activity and interdisciplinary approaches. In one school in Northern Ireland the appointment of a member of the SLT to be 'in charge of STEM' was seen as a positive step, this teacher had himself attended CST network meetings. A teacher in another Northern Ireland school described being given time off to attend meetings, participate in the interview for the evaluation, and support other staff to attend meetings.

As discussed (Section 1), more than one teacher attending CST network meetings was seen by TCs as advantageous; as well as supporting attendance/ participation in CST network meetings this was also found to support dissemination. However, the majority of secondary school teachers contributing to interviews were going to CST network meetings on their own and often working in relative isolation in trying to build STEM capacity in their schools.

Embedding activity in D&T and Science

D&T and Science were identified as the two key departments where STEM is located in schools. Teachers were often focused on their own subject area and shared resources within their own department; the involvement of Heads of Department (HoD) appeared key to effective dissemination. In some instances, resources were shared quite systematically across teaching teams within departments. HoDs were at times acting as gatekeepers to whether resources were used in schools. HoDs had different approaches with some building stores of materials and activities and sharing advice and resources with colleagues on demand; in other departments resources were labelled and teachers had free access.

However, teachers' accounts indicated integrating resources into curricula was not easy or quick to do. For example, challenges identified in science departments include: the curriculum is planned far in advance; teacher turnover makes introducing new material more difficult; resources at times require training teachers e.g. with non-physics backgrounds in particular skills (such as soldering). Lack of time and feeling overwhelmed were also identified as obstacles.

Individual mainstream teachers described some strategies they were using to embed STEM activities, such as modelling lessons and building alliances with science technicians who could help other teachers take up resources in lessons. In some small departments a more collaborative ethos was identified with one teacher describing how she could cascade CST training to the D&T team in her school. However, teachers described very strict schemes of work in some instances that limited the extent to which resources could be used.

One teacher described her MAT had appointed a Head of D&T to be a D&T link across all the Trust schools. CPD days had been set up for D&T teachers across the Trust to enable collaboration which provided opportunities to discuss curriculum and share ideas.

Cross-curricular working

teachers described some sharing of resources beyond their own departments. This included with careers educators. Developing enrichment activities were supporting cross-curricular working in some schools. Middle leaders with responsibility for year groups were

identified as potential allies in using CST resources in an activity with whole year groups. An increased focus on enrichment activity in schools was seen to boost opportunities for developing cross curricular approaches to working in schools. However, in some schools extra-curricular activity was planned and delivered only within individual departments.

TCs and teachers identified benefits in cross curricular teams attending CST network meetings, with one D&T teacher describing attending network meetings with a maths and science teacher whenever possible (though limiting access to CST resources was seen as a disincentive to groups of teachers from schools attending). In Wales the new curriculum was seen to be driving cross-curricular engagement with CST resources.

D&T and Science teachers frequently discussed sharing resources with teachers in other departments but were unaware of whether these had been taken up by colleagues. Lack of time was seen as a major challenge. An additional challenge was that since the pandemic teachers no longer gathered in school staff rooms so there is less opportunity for informal sharing and discussion.

Collaboration between schools

Patterns of collaboration

The role of MATs in disseminating information and resources from network meetings and working with other schools was highlighted in teachers' accounts. Several teachers discussed how their MATs now have aligned curricula which was seen by some as an opportunity to embed resources across MAT schools. However, other teachers were uncertain whether the drive for uniformity in curricula would contribute to or undermine opportunities to integrate STEM activity. In some MATs there appeared to be no collaboration across schools.

Teachers widely discussed using CST resources/ STEM activities with feeder primary schools. TCs and their schools were at times seen as a hub for other teachers. In more collaborative orientated networks, teachers described how being part of the network had led to their linking up with other local schools with several teachers describing how they were offering support to local primary schools. Some TCs were deliberately creating and promoting links between teachers to promote mentoring and support. For example, lack of expertise in computing was highlighted by TCs and teachers as an issue in primary schools, and one TC had drawn on network teachers to provide expertise and mentoring.

In more collaborative orientated networks, strategies were being used to consciously support collaboration between schools. In a few instances, funding from STEM learning for Enthuse Partnerships was used. WhatsApp groups had also been created. Teachers' accounts indicated they found it helpful to develop links with a small group of teachers in their networks. Length of time being part of networks, alongside the deliberate interventions of TCs supported the development of connections and collaborations between teachers.

In networks where TCs were not actively promoting collaboration, teachers were at times attempting to build support/collaborations with other schools more informally. Teachers had been encouraged to share details in some networks, but there appeared to be no drivers to develop closer connections/ to follow up on contacts. One teacher suggested that if the TC were to set up connections between teachers this would help to 'connect people up'. Accounts indicated a clear appetite for closer collaboration with other network schools, with teachers expressing the desire to share ideas about using resources, discuss curricula and share resources. However, without drivers for this collaboration it seemed unlikely to happen organically.

The role of the Collaborative event

Data from TCs and teachers on collaborative events were limited as events had not been able to take place for two years due to the pandemic. A range of different collaborative events were discussed with events often taking the form of regional competitions where small groups of students attended from different schools. Some collaborative events discussed were large events that took significant organisation. Several TCs talked about working in collaboration with other oganisations such as The Institute of Civil Engineers, Young Enigineers and Energy Quest, with Vex Robotics most commonly cited. Teachers' and TC's accounts indicated that a small group of (often between 6-12) students were generally selected to attend Collaborative Events from each participating school. Attendance at the event was sometimes used by teachers in schools as a reward and appeared most often to be directed to students with an established interest in STEM.

Regional competitions between schools were viewed positively by TCs and teachers with these at times being seen to have wider positive impacts on schools. There were some accounts of how organising collaborative events supported collaboration between schools, such as network teachers contributing to the development of STEM days.

Several teachers talked about collaborative events as being the only time they collaborated with teachers from other schools in CST networks, though the extent of this collaboration appeared limited. TCs often appeared to organize events entirely on their own and expressed concerns about making demands on teachers' time. However, collaborative events were seen as valuable opportunities to bring teachers together, providing time for teachers to talk informally, make contacts and to upskill teachers. There were accounts of events being used to develop knowledge and skills amongst teachers such as in curriculum development and programming.

TCs highlighted challenges that work against collaboration between schools including the removal of Local Education Authorities and increased competition between schools.

Take up and use of resources in schools

Teachers' and TCs' accounts highlighted the limited flexibility within the school curricula. Implementing a new activity into existing curricula depends on factors including time for the activity, overall fit with curricula and exam requirements. Teachers working in silos in individual departments is problematic for integrating STEM activity. Implementing a new activity requires teachers to work together and demands enthusiasm as well as teachers' own time and school curriculum time. Considering these constraints, incorporating the resources into lessons is challenging and many teachers use the resources in extra-curricular activity, notably during after school clubs and science weeks, rather than attempting to integrate them in the curriculum in their subject area.

Various uses of resources and the extent of the reach

There seemed to be a difference in the ways and extent of use of resources between primary and secondary schools. In primary schools, teachers usually share the same staff room, facilitating sharing and more extensive use of resources within the school and across year groups. Opportunities to share resources and discuss them with other teachers provided some primary teachers with opportunities for their creative integration into the curriculum.

In secondary schools, cross subject use of resources appeared to be more limited, with teachers noting this was more problematic when there was not a designated STEM lead in the school. Teachers' accounts indicated that some resources, and particularly those with shorter activities, were easier to include in lessons.

The use of activities during STEM weeks and in after school clubs was common in teachers' accounts and teachers particularly valued resources for STEM clubs. However, STEM clubs and other activities that involve voluntary participation can raise inclusion concerns as they often attract students who are already high attainers, positively orientated and interested in STEM subjects. There is an additional issue that STEM clubs can exclude students who are unable to stay after school, for example due to lack of transport.

Compatibility with the school curriculum

Fitting resources into the curriculum within individual STEM subject areas was not considered easy as it can require considerable changes to the existing curriculum. Pressures on teachers around exams and exam groups and rigid set timetables work against embedding activity in school curricula. Teachers in both primary and secondary schools described feeling constrained by the content of the curriculum and often appeared to struggle to use resources despite seeing their benefits.

The topic of resources has had an important role in teachers' decisions to use activities. Some resources were reported to be a very good natural fit and timely (e.g. Engineering in Pandemic). D&T teachers often appeared to find it easier to embed resources into the D&T curriculum than other subject areas.

Teachers discussed finding some resources too advanced (either in terms of the information or in terms of required activity such as coding) and more suitable for older students or higher attaining students.

Characteristics of the resource packs

The fun and engaging nature of resources was widely found by teachers to raise students' interest. Resources were seen to be particularly useful in providing an "everyday" and interdisciplinary perspective to science. A benefit of resource packs identified was their ease of use, especially when they are individually packed and provide hints and supporting material such as video links.

Other Challenges

Whilst identifying significant benefits of resources, teachers identified implementation challenges. These included the limited number of packs available which made their use in larger classes and regular lessons more challenging. Teachers discussed finding longer activities more difficult to integrate into their teaching, preferring shorter activities that they could more easily use in existing lessons. Limited available time also posed challenges for teachers, as in order to effectively integrate resources teachers needed time to both familiarise themselves with resources and for discussion with colleagues. The IT and science skills required by some resources posed challenges for some teachers. Another issue raised was the delay between training and receiving kits, which meant that teachers found it harder to use resources as they had forgotten details or lost motivation in the interim period.

Impact on practice and teachers

Connecting different STEM subjects

A salient aspect of the CST programme and its impact on teaching practice identified was connecting different STEM subjects via project-based learning; teachers and TCs pointed out benefits of this "big picture" project-based learning approach for teachers and students. Participants also highlighted the support provided by the programme for contextual and cross-curricular learning and the role of the resource pack and related activities in this was widely acknowledged.

Facilitating STEM careers

Teachers and TCs frequently discussed the facilitating role of kits in initiating crucial conversations around STEM careers and subject choices with students, and the

corresponding confidence developed. One useful aspect was specifically facilitating “engineering” career conversations which is difficult for some teachers as their exposure and experience in engineering is often very limited. Teachers widely discussed how resources and activities have effectively raised students’ awareness of a wider variety of STEM careers, particularly in engineering.

A significant benefit of the CST programme noted by several teachers was its impact on engaging more girls. The opportunities provided for girls to work with exciting kits and activities were found in some instances to effectively drive their choice of STEM subjects for further study.

Change in student attitude and behaviour

A theme frequently mentioned by teachers was how activities were improving student engagement. Teachers highlighted how students, particularly boys and those typically seen as less interested, have been excited and energised by the resource packs. While improvement in student engagement in general was reported, teachers also pointed out how resources support inclusivity by involving less academic or disadvantaged students. Teachers and TCs also noted that some of the resources, because of their relevance and design, had captured the attention of students which then led to outside school engagement with parents.

Pedagogy support and change in teacher practice

Several TCs and teachers highlighted the curriculum enriching aspect of kits and corresponding activities. Some teachers were integrating activities that they would have previously considered extracurricular into lessons; it was suggested that this enriched lessons and had a larger scale impact in schools**.** Another way TCs and teachers reported lessons were enriched was through gamification. Accounts indicated that bringing games into classrooms was enjoyed by both students and teachers.

Teachers’ accounts, particularly those from more collaborative orientated networks, indicated sharing best practice has been a major benefit of attending network meetings. Opportunities to talk informally about classroom practice has supported teachers in identifying improvements to subject specific pedagogies. Teachers widely discussed how the programme had ‘upskilled’ them, particularly with regards to engineering, providing them with practical hands-on examples of what engineers do that in turn can be shared with students.

Increased Teacher confidence and self-efficacy

Teachers commonly highlighted the motivational and practical aspects of the CST programme. These programme attributes helped to build confidence and self-efficacy in STEM teaching; enabling teachers to bring up-to-date content into their practice using the resources provided by the programme. Teachers discussed being inspired by other participants in network meetings. New resources, attending meetings and training helped teachers understand complex content and technology, and saved time that would normally be required in learning and implementing new material.

Some teachers notably benefitted from the technological resources provided through the programme. These teachers had not previously had sufficient subject knowledge or confidence to bring this type of material into their classrooms but developed confidence and increased self-efficacy through attendance at meetings and training, and through using resources in their classrooms.

Teacher career support

Teachers and TCs identified a number of career supporting aspects of the programme. Network participation was seen as an important professional development opportunity included in performance reviews at some schools.

The opportunity network meetings provide to interact with teachers in other disciplinary areas and develop their understanding was also valued and was seen to help teachers taking up leadership roles, such as responsibility for STEM where understanding of different disciplines was important.

Learning new skills that expand teachers' horizons and having opportunities to continue to develop professionally through training and dialogue with peers are highlighted as salient benefits of participating in the programme by teachers.

Raising the profile of STEM in Schools

Teachers' accounts indicate several positive repercussions of involvement with the CST programme in their schools. Multiple teachers provided detailed accounts of how the CST programme raised awareness, triggered other STEM activities and supported other STEM events. Two examples include one school working with related local industry and STEM ambassadors, and another getting involved with other local schools, entering competitions and building the STEM profile of the school.

Teacher challenges

A common issue discussed by teachers was time constraints, and that most events such as network meetings take place out of school time and rely on teachers' dedication and enthusiasm to work outside school hours.

A different time related concern related to the curriculum and available lesson time; finding time in lessons to do CST activities was challenging for teachers who felt under pressure to deliver curriculum content in limited available time. D&T was identified as an area in some schools that had been particularly squeezed in terms of available lesson time.

Another challenge identified by teachers was how to make students comfortable with less structured learning and how to support them in performing problem solving. With project-based learning using kits, students are expected to work on a problem without necessarily being given full set of step-by-step instructions, and a few teachers noted that some students, especially boys who are used to more traditional pedagogies, can find this challenging.

Discussion points

This study highlighted both programme successes and challenges. As suggested by earlier evaluations (Kutnick, Good & Gartland, 2018) there is very variable engagement with networks amongst teachers, with some engaging extensively with project activity and others dropping into network meetings on a more sporadic and even one-off basis.

Teachers' and TCs' accounts indicate that the CST programme has had many positive outcomes in schools. Notably the programme has significant reach across the country and has effectively engaged teachers who widely take up programme resources and use them with students in their schools. In comparison to when the programme started, awareness of STEM in schools now appears to be widespread and teachers attending network meetings are keen to promote a STEM agenda in their own contexts. Teachers continue to attend network meetings in their own time, outside school time, because they value the programme, appreciate the resources and opportunities for interaction the network meetings provide. Given the extremely challenging landscape in schools, this is testament to the programmes' ongoing relevance and value to teachers, and the quality of programme resources.

The programme has a number of attributes of effective CPD programmes according to the literature. One key attribute is that it allows opportunities for collective participation and active learning (Desimone, 2009). Teachers are positioned as students (Whitworth & Chui, 2015), have direct experience with programme resources and are able to develop an understanding of challenges students face. They also have opportunities for discussion with other teachers about their practice, supporting them in understanding how to develop approaches and how to embed new resources in their teaching (Cordingley et al., 2015). Programme resources provide teachers with specific teaching

strategies and opportunities to experience these firsthand as well as 'direct instruction in new material' (Wilson, 2013: 310) so that they feel equipped to use resources immediately with students in their schools (Wilson, 2013). Teachers also discussed finding programme activities 'educative' (Wilson, 2013), talking about how they learnt a range of new things, including about new technologies, engineering and engineering careers.

The programme has been sustained and long term (Desimone, 2009; Cordingley et al. 2015). Teachers' accounts indicate that attending training and trying out activities with students in schools effectively develops their self-efficacy and confidence in using new STEM approaches with students (Whitworth & Chui, 2015; Kutnick et al. 2022). The programme additionally connects teachers to wider Professional Learning Networks (Brown & Flood, 2020), linking them with other STEM providers in their areas and nationally. This was found to have significant impacts in some schools who, as a result of engagement for example with STEM competitions had embraced STEM as a whole school agenda and effectively embedded STEM across the curriculum.

Teachers' accounts, however, highlight a number of obstacles for the programme. The programme's ambition to promote the application of engineering in the context of STEM subject areas in secondary schools is hard to achieve on a large scale in a secondary school landscape where there are stark divisions between subject areas, a packed knowledge focused curriculum and preoccupation with end point assessments. Secondary teachers were focused on their own subject disciplines and did not appear to share clear goals in terms of promoting the application of engineering or promoting interdisciplinary STEM approaches in their teaching. Constant reform and a post covid landscape have contributed to teachers feeling stressed and overworked. Empty school staffrooms present additional challenges, reducing opportunities for informal discussion and collaboration. The arrival of Multi Academy Trusts appears to present some further obstacles, with a number of schools having their curricula fixed at a trust level, preventing teachers from making changes to curriculum content. However, MATs also present opportunities to work with interdisciplinary groups of teachers from across MAT schools and embed project activity in the curricula of whole groups of schools. TCs' and teachers' accounts, reflecting findings in the wider literature (e.g. Opfer & Pedder, 2010; Whitworth & Chui, 2015) indicated that there is a need to engage with Senior Leadership Teams in schools, to ensure that they champion CPD activity with staff and promote engagement with STEM across schools.

Whilst teachers' and TCs' accounts indicate that in primary schools, and secondary schools in Wales, teachers can adopt a holistic approach to embedding STEM activity, the separation of STEM subjects in secondary schools makes this approach much more challenging. Teachers in secondary schools often struggled to embed project activity into curriculum lessons; there was some subject variation with D&T teachers generally suggesting resources could more easily be used within the D&T curriculum than other areas (there were no accounts of resources being used in Maths lessons). Teachers accounts indicated that some teachers, especially in Maths and Science, struggle to adapt their classroom teaching to the more project-based learning/student centred approaches outlined in resources. TCs' and teachers' accounts highlight the value of working with middle leaders, Heads of Department (HoD), to effectively apply engineering in STEM subject areas in secondary schools. HoDs were able to ensure teachers attending network meeting act as 'bridges' (De Lima; 2010) and share resources and approaches with colleagues in schools. Involvement of senior and middle leaders and the engagement of interdisciplinary groups of teachers with programme activity, rather than individual teachers, also help to address problems of attrition of schools from regional networks due to individual teachers changing jobs and moving schools.

Resources were most commonly used in extra-curricular activities. In some schools, inclusive extra-curricular activity was offered engaging whole year groups, and project resources could be effectively integrated into these programmes. However, in a lot of schools, the focus of resources in extra-curricular activity presents problems for the inclusive agenda of the programme, as often students self-select to attend extra-curricular activity. This means engagement with project resources is frequently narrowed to groups of students who have an established interest in STEM/ are relatively high attaining and are often relatively advantaged in socio-economic terms and have existing high levels of science capital (Moote et al., 2021). Some schools discussed how project resources motivated lower attaining and disadvantaged students, however, there appears to be limited focus on middle attainers who are often underserved in schools (Hodgson & Spours, 2020; Hodgson & Spours, 2014; Archer, DeWitt & Dillon, 2014)

Teachers' and TCs' accounts also indicated the format of network meetings often fails to provide sufficient support for teachers to effectively embed STEM activity in the school curriculum. Sessions, especially those held online, were frequently information heavy with each session including information about the CST programme, information about other available STEM activity, and opportunities for other STEM providers to inform participants about their activities as well as an introduction to new resources. The opportunities for teachers to physically engage with project resources and to discuss and reflect on their practice with other teachers were limited. There were limited or no opportunities for teachers to discuss their use of previous resources. Such reflection, collaborative working and opportunities to think deeply about practice are considered important to effective CPD (Borko et al., 2010; El-Dehaidy & Mansour, 2015; Nelson et al, 2015; Cordingley et al., 2015; Kennedy, 2016; McChesney & Aldridge, 2019; Liou et al.,2020). Opportunities for teachers and TCs to share and reflect on their practices supports teachers in developing and embedding student centred learning and teaching approaches in their classroom practice (Dogan et al., 2015; Baines, Blatchford & Kutnick, 2017). As Nelson et al. (2015) suggest, teachers need time, space and opportunities to develop trusting relationships so that they have deep conversations with other teachers. Such reflective activity and the building of trusting relationships was additionally hindered by changes in groups of participants and high numbers of new people attending network meetings, this attendance was often fueled by close links with STEM learning partnerships. The success and expansion of the CST programme may have contributed, as De Lima (2010) suggests, to CST networks becoming more rigid and formal in approach.

The structure of networks often included a small core group who know each other well, with newer members at times more isolated and disconnected. The wide mix of teachers in networks who were from different schools, at different points in the career, with different levels of experience, from different subject areas, and at times from different sectors appears to contribute to lack of naturally forming connections between members. However, there were examples in TC and Teachers' accounts of strategies that were effective in supporting teachers to reflect on their practice and work collaboratively, with examples of this leading to changes in individual teachers' practice as well as wider practice in schools. Some TCs used network meetings to provide models of how resources had been used in their own and other schools, which effectively supported the development of their network teachers' own sense of self-efficacy (Kelley et al., 2020). In some collaborative orientated networks TCs deliberately fostered opportunities for teachers to work collaboratively and share practice. A few TCs were consciously using the social capital within their networks, making connections between members so that expertise within the group was shared (Khalil et al., 2016; Loui et al., 2020). For example, in one network the TC deliberately partnered members of the network with expertise in computing with primary school teachers who lacked knowledge in this area, to support the embedding of computing in the primary school curriculum. Other TCs were deliberately

positioning network members as co-facilitators, encouraging a shared sense of ownership of the network and enabling better support for teachers (Hanraets et al, 2011). The use of WhatsApp and other online and social media platforms were seen to be of value in supporting development of supportive networks and sharing practice (Borko et al., 2020; Wilson, 2013). However, the use of social media platforms was often viewed with caution, seen as too time consuming for TCs to manage and potentially irritating for busy teachers.

What was evident from TC and teachers' accounts was the importance of understanding the particular location, local school landscape, existing networks and opportunities within local areas. The location of CST networks matters, and it is clearly of vital importance to develop an understanding of these contextual and geographical factors when attempting to promote engagement and collaboration within a teacher network.

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