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STEM education in the 21st century: learning at work - an exploration of design and technology teacher perceptions and practices

Abstract

Teachers' knowledge of STEM education, their understanding, and pedagogical application of that knowledge is intrinsically linked to the subsequent effectiveness of STEM delivery within their own practice; where a teacher's knowledge and understanding is deficient, the potential for pupil learning is ineffective and limited. Set within the context of secondary age phase education in England and Wales (11–16 years old), this paper explores how teachers working within the field of design and technology education acquire new knowledge in STEM; how understanding is developed and subsequently embedded within their practice to support the creation of a diverse STEM-literate society. The purpose being to determine mechanisms by which knowledge acquisition occurs, to reconnoitre potential implications for education and learning at work, including consideration of the role which new technologies play in the development of STEM knowledge within and across contributory STEM subject disciplines. Underpinned by an interpretivist ontology, work presented here builds upon the premise that design and technology is an interdisciplinary educational construct and not viewed as being of equal status to other STEM disciplines including maths and science. Drawing upon the philosophical field of symbolic interactionism and constructivist grounded theory, work embraces an abductive methodology where participants are encouraged to relate design and technology within the context of STEM education. Emergent findings are discussed in relation to their potential to support teachers' educational development for the advancement of STEM literacy, and help secure design and technology's place as a subject of value within a twenty-first Century curriculum.

Keywords

STEM, Professional learning at work, Twenty-first century skills, design and technology

Introduction and rationale

The impact of low-performing teachers on pupil progress is severe (Barber and Mourshed 2007) and findings from previous studies (Bell 2016; Penuel et al. 2007) indicate that a teacher's perception of STEM, their personal knowledge, and understanding of that knowledge, is intrinsically linked to the effectiveness of STEM delivery within their own professional practice. In considering this further, it is clear that where a teacher's own subject knowledge, and their pedagogical application of that limited knowledge is also deficient, findings indicate the potential for pupil learning is limited (Rockland et al. 2010).

In order for learners (pupils) to become STEM literate, empirical evidence (van Tuijl and Walma van der Molen 2015) suggests that there are advantages in supporting teachers of STEM subjects to explore ways in which they can best foster mutually reciprocal arrangements for praxis with their counterpart STEM colleagues. This is particularly important for those working within discrete subject disciplines in order to support the creation of an interdependent, cooperative and symbiotic curriculum founded on commonality of understanding.

Driven by the challenges of a changing global economy in a post-industrial era, STEM skills are perceived as vital in securing a nation's economic prosperity (Li 2014; Mc Garr and Lynch 2015). With a 'disconnect' between those who plan to pursue STEM careers and those who demonstrate an aptitude for them fuelling concerns over labour shortages (Mitchell 2015; Ritz and Fan 2015), the development of STEM education is perceived globally as being fundamental in addressing the deficiency (Bassett et al. 2010).

Ontologically this work builds upon the premise that design and technology is an interdisciplinary educational construct; a subject not fully understood by those working outside of education (Bell et al. 2017). Whilst design and technology has much to offer in supporting the effectual development of STEM literacy, as a subject it is frequently marginalised and its potential not realised (Bell 2016). Consequently, design and technology is not viewed as being of equal status with the STEM disciplines of mathematics and science (Benken and Stevenson 2014).

In secondary age phase education in England and Wales design and technology has been omitted from the English baccalaureate (EBacc), a collective of subjects being drawn together to provide a national performance indicator and measure of learner success (DfE 2016). It is further marginalised by another recently introduced performance indicator; *Progress 8*, the mechanism by which school attainment in England and Wales is comparatively measured in league tables (DfE 2017). Side-lined from education policy and persistently excluded from STEM focussed initiatives (Morgan 2014), design and technology is evidently STEM's poor relation.

This marginalisation has led to inequity which is manifested in less allocated time for design and technology curriculum delivery and also in restricted access to funding for teachers of design and technology to undertake subject specific in-service training and professional development. In practice this expedites the continued silo nature of individual STEM subjects making it difficult to capitalise on opportunities for symbiotic curriculum delivery. That is not to suggest, however, that an integrated STEM curriculum would be advocated, as the introduction of a given dualistic curriculum may serve to exacerbate current difficulties and in practice this may be further counter-productive. Having established participants' personal understandings of STEM pedagogy, this study seeks specifically to discover:

How do teachers of design and technology acquire further STEM knowledge, and subsequently embed it within their own practice?

Methodological Approach

The methodological approach adopted for this small scale explanatory study is one that aligns with the principles of constructivist grounded theory. This method utilises an abductive methodology, combining both inductive and deductive knowledge generating procedures, with reasoning emerging from scrutiny of the data collected.

In her work Charmaz (2006) describes how by utilising this approach theoretical concepts are constructed rather than being 'discovered', subsequently explaining the impact that a researcher's biographic and reflexive relationship to data can have on the outcomes from a study. In this study participants were encouraged to consider the position of design and technology as a subject of worth within both the curriculum and STEM education. In so doing this ensured that the research outcomes focused on the participant's substantive insights are more representative of the realities, perceptions and experience they share.

In practice this approach encouraged participants to relate the positioning of design and technology within their understanding of the wider field of STEM education. Utilising this approach, insights were co-constructed between the researcher and those being researched, and thus this study presents the research participants as agents of change, working within the confines of a prescribed curriculum.

The Research Cohort

At the time of their involvement all participants were in-service teachers, engaged in the facilitation and delivery of STEM education within secondary age phased teaching (11-16 years of age). For the purposes of this study secondary age phase STEM subjects were defined as being those outlined in statutory curriculum documentation, specifically; Mathematics, Physics, Chemistry, Biology, Design and Technology and Computer Science. The study engaged eleven practising design and technology teachers who were, at the time of participation, working within educational settings located across England and Wales.

Participants were drawn from a wide range of educational settings and as far as was possible were selected in order to ensure as diverse a range of personal and demographic characteristics, not only in terms of their individual design and technology discipline, but with regards to their personal attributes such as their, age and gender. Within the cohort, the gender breakdown of research participants was almost equal with five males and six females being engaged in the study. Participant's ages ranged from 26- 59 years, and years of service from 3-34 years. With respect to teaching qualifications, four held Post or Professional Graduate certificates of Education (PGCE) with one holding a Post Graduate Diploma. Five held a BSc (Hons) with Qualified Teacher Status (QTS) and one held a Certificate of Education. Of the research cohort, nine participants were qualified to teach children aged between 11-16 years, and two were qualified to teach age phases 7-16 years. Five held additional departmental or whole school responsibilities, and seven were active in supporting their respective institutions extra-curricular STEM curriculum.

The table below indicates which design and technology disciplines individual participants aligned themselves as being confident to deliver, which is accompanied by the geographical location and a brief outline of the participant's institution. The table also makes clear within which research phases of the study individual participants were engaged (Table 1).

	Design and Technology Discipline	**Institutional detail**	**A**	**B**	**C**
Participant 1	Food, Graphic Products, Product Design and Electronics	North West England, Urban, Maintained (11-19)	✓	✓	✓
Participant 2	Textiles, Product Design and Electronics	North West England, Rural, Maintained (11-16)	✓	✓	
Participant 3	Engineering, Resistant Materials and Product Design	North East England, Rural, Academy (11-16)	✓	✓	✓
Participant 4	Graphic Products and Product Design	South East England, Urban, Academy (11-16)	✓		
Participant 5	Graphic Products, Product Design and Electronics	North West England, Urban, Free School (11-16)	✓	✓	✓
Participant 6	Engineering, Electronics and Product Design	The Midlands, England, Urban, Academy (11-16)	✓		
Participant 7	Food and Textiles	North Wales, Rural, Academy (11-19)	✓	✓	✓
Participant 8	Electronics, Product Design and Resistant Materials	North West England, Urban, Free School, (11-19)	✓	✓	✓
Participant 9	Product Design and Resistant Materials	North Wales, Urban, Maintained (11-16)	✓	✓	✓
Participant 10	Graphic Products, Food and Textiles	South West England, Rural, Maintained (11-16)	✓	✓	
Participant 11	Product Design and Graphic Products	South East England, Urban, Academy (11-19)	✓		

Footnote
A maintained school is state-funded by a local education authority. Academies and Free Schools (also known as an independent state funded school) are publicly funded directly from central government and operate outside of local education authority control (GOV.UK 2017).

Participant engagement key

A	Semi-structured interview
B	Group Interview
C	Validation group interview

Table 1
Research participants' demographical characteristics and attributes

Working within the principles for sampling within grounded theory advocated by Morse (2007), initially four participants were selected on the basis of their accessibility using convenience sampling (Richards and Morse 2007). As the basic trajectory of the research emerged, utilising purposeful sampling, four additional participants were selected based upon their ability to provide rich and varied accounts (Geertz 1973) of the phenomena under study. Each was selected based on their perceived ability to provide specific responses that sought to link categories and contribute to the emergence of a meaningful outcome.

Data gathering

Coterminous data was gathered from eleven semi-structured interviews, two focus groups and one validation interview. During each data collection phase methods advocated by Charmaz (2014) were utilised with care being taken to ask exploratory, rather than interrogative questions. This approach was structured in such a way as to encourage participants to explore and subsequently reveal their own values and beliefs in an honest and open way. In seeking to validate their espoused responses, participants were asked to recall examples and contextualise their knowledge within them.

All participants (11) were engaged in the semi-structured interviews (Table 1) the duration of each being between 35-45 minutes. Following on from the individual interviews, in order to saturate the conceptual categories, two focus group interviews were utilised in order to gather additional collective discourse. During this phase, eight participants were recalled in two groups. Having been introduced to the preliminary findings from the semi-structured interviews, participants were encouraged to interact with one another and to exchange illustrative anecdotes to comment and critique on others points of view. The focus group interviews lasted in duration between 55-65 minutes and this discourse enabled participants to discuss issues that they felt were particularly important to them, which according to Morse supports the resolution of 'conundrums or ambiguities that the researcher may have about the emerging model' (Morse 2007:241). Data collection was undertaken until coding procedure analysis determined that there was saturation of the emergent insights.

Finally, in order to support verification, and the subsequent generation of substantive insights a group validation interview that engaged six participants (Table 1) was held. Here specific attention was paid to how participants responded to commonly held perceptions and shared experiences. In accordance to the work of Hardy and Bryman (2004) the aim of this interview was to study the processes whereby meaning was constructed collectively within the group.

Ethical considerations

Prior to engaging in the study informed consent was obtained. A single researcher conducted the research therefore issues relating to inter-rater reliability, the method used to assess the degree to which different observers consistently assess the same phenomenon, were not applicable. However, this approach itself has the potential for bias from the perspective of the researcher's own ontological perspective and position. Of the cohort the researcher knew four participants as they had previously been student teachers. There was no link between the researcher and research participants in terms of having undertaken previous studies or research projects. In line with the chosen research method, the co-construction of knowledge between the researcher and those being researched was encouraged to help ensure that outcomes were representative of the realities of the participants' perceptions and experience. To support the elimination of bias, research was conducted in three distinct phases with the latter two being focus group based, a mechanism which itself sought to validate research findings with participants themselves.

Interviews took place in a neutral setting at a time convenient to the participants with adherence to the ethical guidance described by British Educational Research Association (BERA 2011). Semi-structured interviews encompassed methods advocated by Charmaz (2014), Bowden and Green (2005) and Kvale (1996) with follow up email discourse occurring as necessary in order to clarify and validate transcribed data. Interviews and focus group discussions were recorded and transcribed verbatim. Care was taken to accurately record responses in order to avoid misrepresenting the given meaning assigned, and so as not to influence the data by one's own pre-conceived ideas.

Analysis and presentation of findings

During analysis, a combination of grounded theory procedures (Glaser 1978; Charmaz 2014) were adopted which involved the following stages of coding:

- Open coding
- Substantive Coding
- Theoretical Coding

This approach enabled the identification of a preliminary set of ideas (or codes) which, following the process of open coding, were subsequently used to develop substantive codes. Theoretical sampling helped to keep data gathering and analysis closely related to the realities of the participants' perceptions, which according to Seale (2003) and Cresswell (1998) add validity and reliability to the research outcomes. Through analysis of the two focus group interviews, categories emerged and were then further refined, following which they were authenticated through means of the group validation interview. This process sought to support the verification of the categories (Morse 2007). Throughout, analysis was supported by the use of memo writing, and focused on how aspects underpinning the study related to participants' experiences of their practice and represented some of the challenges found within their working environments. Constructing explanations that help describe the work under investigation, analysis focussed upon how aspects of this study related to what was happening in practice.

Following analysis of the data, in accordance with procedures advocated by Braun and Clarke (2013) and Finch (1987), three vignettes were built up from participants' responses. The vignettes represent participants' perceptions of their experiences in developing or acquiring new STEM knowledge and how subsequently they seek to embed it within their own practice. Each vignette describes briefly the biographical background, participant experience and their perceptions on learning, personal development and STEM related practice within their respective settings.

Vignette 1
Debbie (Head of design and technology in an 11-19 age phase education setting)
Debbie has been working to incorporate STEM into lessons across her D&T department. She describes herself as having a predominantly *"self-taught"* knowledge of STEM, which she is very keen to develop. Debbie joined her current school eight years ago, having previously worked in industry. She holds a textile related product design degree and has worked hard over the last few years to ensure her "...*knowledge across the range of design and technology remains strong*" but by her own admission has a "very limited *knowledge of maths and science.* Three years ago, when she became head of department, a very experienced member of staff retired and as not replaced. To prevent his subject from being squeezed from the curriculum, Debbie developed her electronics expertise, which she feels she is now able to confidently teach.

When articulating how she developed this new knowledge Debbie explained that as a new Head of Department, she had access to a small training budget. She attended; "*a couple of courses in electronics"* and noted that *"this is how I became aware of STEM and initially I must be honest, with cuts to my budget, I was interested in the potential that STEM held to my department as a funding stream*". In returning to school having attending the course, she disseminated knowledge gained informally to her staff and some colleagues from neighbouring schools. After searching the Internet, Debbie sourced a free course which she was able to complete in her own time online, which led to her subsequent success in accessing a small funding grant. She used this to set up a STEM club for pupils in Key Stage 3 *"to help boost option number at Key Stage 4"*. The access to funding gave a much-needed boost to her subject's profile in school. She enlisted the help of a design and technology colleague and two Newly Qualified Teachers (NQT), one from maths and the other from science, and with the support of her Head Teacher she is organising a second whole school STEM day.

Through her participation with this study, Debbie's awareness of her role in supporting the development of her colleagues in the evolution of STEM education within her self-styled network group was heightened, and through reflection she could see how "...*my competence and confidence in STEM increased after I attended the training"*, but she was clear to stress that this was not because of the workshop itself: "*the confidence came from sharing ideas when I got back. I couldn't afford to undertake most of the ideas I saw, we just haven't got access to that kind of money – but in sharing what I learn with others, collectively we came up with ways of adapting some of the ideas, not only to come in under budget but redesign the projects to meet the needs of our kids.*"

Debbie facilitates STEM learning, but was the least confident about her contribution to STEM education, and considers herself to be a novice, believing firmly that she gains as much from sharing her knowledge, as colleagues obtain from her.

Vignette 2
Paul (A design and technology teacher working in an 11- 16 age phase maintained secondary school)
Paul qualified as teacher able to work across both primary and secondary age phases and has been teaching for five years. As a result of his route into teaching the integration and collaboration with, and between, individual subject disciplines are familiar to him, and a concept he is comfortable with.

Coming from an undergraduate teacher training background, whilst not having received any formal STEM training, Paul has skills in all areas of design and technology as well as a strong working knowledge of both science and mathematics at Key Stage 2, which he recognises is an advantage. Currently Paul is teaching electronics and product design although he has taught food. He also delivers design and technology to a number of local primary feeder schools. At school, he has been involved in the organisation and delivery of the school's STEM club since taking up his post as a NQT. Paul helps run the club with two colleagues, both from the science department, one of whom is the schools designated STEM coordinator.

The fully funded club aims to attract high ability Year 9 pupils, running during lunchtimes and sometimes an evening each week. Paul receives no additional payment for his work but explained that he enjoys taking part. Paul explained that "*sometimes it's hard to get a project that involves all elements of STEM…especially as we don't have a mathematician in our team*" but he added that he did not feel it was necessary to do so all of the time, but acknowledged it would be advantageous to incorporate higher levels of maths into club activity. Whilst this is a well-funded club, so far Paul *"hasn't been able to access any formal training to support him in this role"*, but he is clearly confident. When asked how he achieves this Paul explained that he *"picks up* *information from Simon [the STEM coordinator] when he comes back from the odd training course... but mostly I do stuff in my own time, I use the Internet to keep up to date. There are loads of really good free courses like Future Learn or MIT open courseware you can complete, where often you can get as much help from the twitter feeds and online discussion groups. Sometimes you have to be a member of the association to access ideas and resources [such as the International Technology and Engineering Educators Association (ITEEA)] but it can be worth the cost. I'm also involved with a local design and technology subject network group [facilitated by his former university] and through that the club was able to go to university and take part in a STEM day… I suppose if I need help usually I tend to ask my subject network people first".*

The club also plans to arrange other visits and to take part in national competitions. When asked how he learns best, Paul isn't able to comment on formal STEM training, but as he explains *"I'm confident in my STEM work. I enjoy collaborating with science, and using my skills from Key Stage 2. Simon comes back with some ideas that we can adapt but mostly the best ones we end up using come from my subject networks, they tend to be more practical. Kids won't come to the club if all they do is sit and cover theory. I find that I use a lot of what we do in the club …spills over from the club into my day to day teaching…. a main aim of the club at the moment is to introduce to the pupils to projects which involve smart materials, and conducting experiments with them...I came across the materials when I trained to teach, but they are expensive so haven't actually used them yet in my regular teaching".* Work with smart materials enables the children to explore the properties of smart fabrics, thermo-chromatic and photo-chromatic pigments. As Paul explains *"pupils explore the properties and scientific principles behind them... they are encouraged to comment on STEM principles such as the changes and reactions to the materials when being used, making notes on advantages and disadvantages...before considering how they could be usefully applied in design and technology".*

Vignette 3

Dave (A design and technology teacher based within an 11-16 age phase academy)

Dave has taught resistant materials and product design for fifteen years, holding an engineering degree, he moved from industry into teaching via completion of a PGCE in design and technology education. In this vignette, we explore a case where design and technology moved from its own department and teaching space, into an integrated science and technology building.

As Dave explains, due to a lack of resources such as no CAD/CAM facilities, coupled with restrictions to pupil option patterns, a number of design and technology staff left his school limiting the range of design and technology offered. Dave found it progressively more difficult to cover the examination specification, and with no access to funds commented that "*...it definitely had an effect on my examination results... the situation was limiting pupil progress and moved me away from the sort of technical work I wanted to do*".

Following the move to a new building, despite initial reservations about being housed in a shared facility with science, things improved. Dave recognised that it has led to the development of links between design and technology and science and opened up exciting genuine collaborative possibilities. With an engineering background Dave commented that "*everything I do is STEM, it's my background …and I'm very keen on STEM work... and believe that combining design and technology with science and maths knowledge helps the children think about everything in a much broader way*".

Dave is frustrated that engineering and design and technology *"…the bedrocks of STEM are always second best"*, explaining that from his perspective these areas have to *"fight for curriculum time"* and the only way his department acquires access to funding is through the science department. There is a STEM club at Dave's school, but it isn't something he contributes to regularly. He explained that it is staffed by teachers from the science and design and technology disciplines, a strategy that Dave believes *"...allows both departments to work together*", but Dave prefers to run his own extra-curricular STEM activity and is currently heavily involved with the F1™ Challenge, a global multi-disciplinary challenge in which team's design and race miniature Formula One™ cars, and commented that his STEM club colleagues were "*...very excited about this".*

During both face-to-face interviewing and contribution to the focus group discussions, Dave stressed how he underpinned all aspects of his design and technology work with STEM. Possibly because of his engineering background, even if he *"could get onto a course"* Dave expressed no desire to undertake any *"formal"* STEM training, preferring to keep up to date *'by himself'* via the internet. Dave was the most confident in discussing STEM, and frequently coupled the teaching of design and technology to real world applications and employment. Dave's work has clear links to both maths and science, and whilst *"the connections are not always made explicitly to pupils",* he was keen to stress that through his day to day teaching he regularly engages large number of pupils during mainstream lessons in STEM activity, which, as he pointed out *"is unlike the majority* *of STEM activities which are accessible only to a handful of pupils who are able to attend the extra-curricular STEM clubs".*

Presentation of findings

Following iterative analysis of the data and abstract categorisation of the nascent codes, substantive insights emerged with, as the vignettes illustrate, participants engaged in this study acquiring STEM related skills, knowledge and understanding via a variety of multi-modal approaches. It is important to note the mode of learning is not a fixed trait, and while there is overlap between the categories, the predominant characteristics of each approach to knowledge acquisition may be aligned and grouped as follows:

1. *Formal* defined as intentional, formally convened training and organised meetings
2. *Informal* defined as informally convened training, meetings and physical and virtual networking
3. *Independent* defined as autonomous, self-directed, self-regulated learning

Building upon the vignettes, in line with the study's methodological approach, the next section of this paper presents the research outcomes within the context of relevant literature relating to how people learn and acquire STEM skills, knowledge and understanding.

Formal Learning

Within this study, as illustrated predominantly within vignette 1, *formal learning* is defined as learning occurring at, during or because of sanctioned work activity, typically occurring through formally orchestrated training events and meetings. Characteristically, this method of knowledge acquisition requires participants [registered] physical attendance and engagement at a pre-scheduled course or external conference, face-to-face meeting or training session. If required, funding for travel and accommodation is secured in advance and a fee paid in order to attend. This approach would also include formally convened professional development, for example: instances where schools propagate self-improvement and make formal arrangements through collaborate networks in order to help support teachers to learn from each other.

Where learning occurs formally in this way, the method of knowledge acquisition reflects the notion of cultivating communities of practice, whereby putting conditions in place knowledge acquisition is likely to occur and as such organisations can plan for Legitimate Peripheral Participation (Wenger et al. 2002). As an approach, this represents a shift away from original work undertaken by Lave and Wenger (1991), which fostered the term Communities of Practice and focused upon apprenticeship as a learning model in which situated learning is embedded and within which activity that is unintentional rather than deliberate.

In this study, only two participants reported having accessed this form of learning within the last five years. The majority of participants (9) reported limited opportunities and difficulty in securing access to funding for formal learning, particularly when compared to their peers working within other STEM subject disciplines notably science and mathematics. Equity of access was perceived to be an issue of significance for eight participants, with the majority citing hierarchal selection procedures as a barrier. As a direct consequence, prohibited access was perceived by almost half of the participants (5) as being divisive and counterproductive in supporting STEM colleagues to work together in a collegiate way.

Other issues arising from this mode of learning were cited by participants as being costly in time away from the classroom, impact upon learners and financially to the school by which the teacher is employed. Furthermore, professional development of this type is by its nature limited to small cohorts as participants within this study noted, significantly restricts the potential for the dissemination of worthwhile ideas, knowledge and understanding. The limitations in relation to wider dissemination are potentially compounded as participant perceptions also highlighted that in some instances, post attendance the person who attended the formally convened course or conference commonly sought to remain the gate keeper of the 'new' knowledge. Within this study the majority of participants (8) held the perception that this retention of knowledge would in some way afford some privilege of status, or advantage over others. The same participants also stated that in these instances dissemination was frequently undertaken through formal static and didactic dissemination mechanisms, which served only to reinforce division between the STEM subject disciplines.

Finally discussing formal learning the majority of participants (10) also reported that whilst courses of this nature were useful to spark ideas, there was a gap between theories espoused and their direct practical application and in order to implement aspects of this training locally, project ideas frequently required significant adaption.

Informal Learning
In this study, *informal* knowledge acquisition is defined as occurring when skills and knowledge are disseminated via informally convened training, meetings or networking. Methods of dissemination cited by participants included occasions when skills and knowledge gained via formally convened training were disseminated informally, in an open, collegiate way.

As an approach, findings indicate that this category is characterised by the utilisation of heuristic devices such as corridor conversations and other similar '*ad-hoc*' information sharing mechanisms. Learning is not necessarily consciously planned, and frequently unintended learning occurs. Examples cited by participants within this study include both physical and virtual 'meetings' occurring both in, and beyond, colleagues own immediate workplace boundaries. An important feature of the *informal* learning category is the co-construction of new knowledge between a network of colleagues, with both the facilitator and learner acquiring new skills, knowledge and understanding. As illustrated largely within vignette 2, to an external observer it may be difficult to see what more experienced members would gain from participation, but as newcomers to the groups gain in 'wisdom' established members gain access to new concepts and ideas (Hildreth and Kimble 2004). Knowledge morphs, and is re-created equally by both parties. The boundaries between learning and work dissolve (Littlejohn 2016) and as new knowledge develops, outcomes from this study suggest it does so within the context of the practice within which it has been created.

This provides the opportunity to harness the professional knowledge that the participants' themselves create, an area explored by Hargreaves (1999) and Gibbons et al. (1994). Where drawing upon their tacit knowledge (Eraut 2000), findings from this study indicate that within this category participants construct new knowledge socially within the context and culture it was learnt (Brown, Collins and Dugid's 1989). This leads to the emergence of a deeper understanding of the phenomena being investigated, which is developed directly from participants' day-to-day experience.

In line with the literature, outcomes from this study would suggest that within virtual environments membership is achieved through active participation, however, for effective communication to take place group members need to be sympathetic and open to new ideas. By working together in pursuit of a common endeavour, mutual trust evolves and individuals combine to become an extremely effective homogenous cohesive working group. Findings from this study suggest that this method of knowledge acquisition creates diverse opportunities for participation, where despite being at differing stages of their understanding, individuals share ideas with each feeling able to contribute. Knowledge is distributed and developed equally. Information shared is unconfined, and according to Dalkir (2013) and Duguid (2005) the learning that takes place is limitless.

Independent Learning
Within this study *independent* is defined as self-directed, autonomous learning. Learning that takes place by an individual independently in order to acquire STEM related skills, knowledge and understanding.

Independent learning may involve traditional orthodox forms of research, for example the use of libraries, galleries or museums, or practical preparations to hone applied skills. However, as shown within vignette 3, findings from this study would suggest that the majority of *independent* learning takes place beyond the boundaries of the immediate physical workplace. Learning occurs rhizomatically (Cormier 2016), which includes approaches such as the use of Open Educational Resources, Massive Open Online Courses (MOOCs), online Internet searches, and the visitation of virtual spaces. Via the employment of these methods to gain new skills, knowledge and understanding, participation is autonomous and learners are highly self-regulated. Often born out of pure self-interest, a desire [or need] to either up-skill, or to gain in confidence in this category, findings indicate that participants were most likely to work around existing online content, reuse open access resources and take only the knowledge they required. When working in this way learners may be likened to visitors (White and Le Cornu 2011) who dip in and out of online spaces in order to gain the information they require with minimal social interaction. In contrast to learners with low self-regulation, who are more likely to follow a course verbatim and at the end seek confirmation [validation] of their learning via certification, findings from this study suggest that participants working within the characteristics of this *independent* knowledge acquisition set their own goals in order to learn what they want and need to learn. They evaluate their own progress and set new goals and challenges for themselves. By working in this way, when the external structures that control learning are removed and learning is driven by the individual, both satisfaction and learning is increased (Littlejohn et al. 2016; Milligan et al. 2014).

Discussion
Globally the highest achieving education systems focus on teacher quality, investing heavily in the professional development of their teachers (Barber and Mourshed 2007) and it is through this high-quality education and training real improvements in teaching and attainment take place (Sutton Trust 2015). The study of STEM subjects should captivate and engross, but pupils are being switched off and choose to disengage with subject study beyond compulsory schooling. In order to facilitate a culture of effective STEM learning in their pupils, teachers must themselves become adept in thinking across the subject boundaries (Saunders 2006) and become STEM thinkers (Reeve 2015) in order to support the development of STEM literacies.

In the UK, STEM educational initiatives and their associated funding for schools is focused predominantly upon science and mathematics (Morgan 2014). From the perceptions and lived experiences of the majority of participants engaged in this study, the impact of this policy enacted means limited opportunity for design and technology teachers to access funding to attend formally convened professional learning and development. At the grass roots level this inequity, whether real or perceived, would appear to expedite the continued silo nature of STEM delivery within English and Welsh school curriculum.

Teacher learning and development is a complex process (OECD 2013; Avalos 2011), and findings from this study provide an insight into how teachers of design and technology acquire new knowledge, share for development existing STEM knowledge and subsequently embed it within their own practice.

In the current climate, the perception of participants in this study is that access to formally convened STEM training is restricted; especially to those working within the field of design and technology education. Outcomes highlight the difficulties associated with accessing formally convened learning. Costs can be financially prohibitive and from the perspective of participants in some workplaces, selection procedures to secure attendance are perceived as both selective and divisive. Findings also suggest that often before aspects of formally convened training can be adopted for pedagogical use, significant work to localise ideas for individual settings must occur.

In contrast, based upon the perceptions of participants' insights presented here, it is suggested that informal and independent learning provides an effective platform for continued personal and professional learning and development. Whether occurring via physically or virtual networking, teachers can better realise the power of co-learning and discover new knowledge developed through their own physical or virtual knowledge-building communities (de Waard 2015; Liyanagunawardena et al. 2013). Participants in this study perceived these approaches as being a highly effective way to acquire new STEM skills, knowledge and understanding.

Given the applied nature of design and technology, it is perhaps surprising that physical and practical skill development was not at the forefront of discussion.

The delivery of 'hands-on' content via a virtual learning environment is an interesting concept, and one that has been addressed by Best and MacGregor (2015), who experienced success in transitioning aspects of a practical course for pre-service teachers to one hosted online. Similar studies have explored how students' participation in digital and informal learning contexts which sought to explore engagement change with science education in school (Jahreie et al. 2011), and Liestøl et al. (2015), which sought to developed STEM learning via online situated simulations. Specific to this study, findings would suggest participants already in possession of practical expertise were confident to utilise learning environments a means of accessing new knowledge and to apply, assimilate and adapt information in conjunction with their existing practical skills in order to develop new ways of thinking.

Alternative approaches to new knowledge creation
With increasingly available access to new technologies and the progressive utilisation of virtual learning communities, the global landscape for teaching and learning is changing.

In many school's classroom teaching is a solitary activity, increasingly so for many design and technology colleagues where quite often a teacher maybe the only specialist in a setting. Within this context there is no doubt that the adoption of new modes of learning may provide teachers with a range of opportunities to enhance their STEM knowledge, but for this to happen teachers need to be both competent and confident in the use of technology in order for best practice in learning and teaching to be shared.

With attention directed toward technology as a tool to facilitate the transformation of teaching and learning in the 21st Century, there is a relentless optimism around its potential for educational use (Laurillard 2014; Lund and Smørdal 2006). However, unlike an increasing number of their students who are 'born digital' (Akhtar et al. 2015) and have the ability to find almost anything, anytime, anywhere, many teachers need to be supported to develop their understanding of online literacy, in particular, how teaching and learning changes when new technologies are used (Hökkä and Eteläpelto 2014; Beetham and Sharpe 2013).

In order to avoid over promises and under delivery, innovation in new approaches to learning should not be confused with novelty, nor should it be assumed that pedagogic innovation is a pre-requisite for excellent teaching (Armellini and Padilla Rodriguez 2016). It is also important for teachers to recognise that innovation in one system may not be in another (Vieluf et al. 2012) and many technologies currently perceived to be innovative are hybrid versions of existing technology, with new pedagogies arising from them.

Findings from this study indicate that participants are increasingly comfortable with the notion of developing their practice informally and independently, learning through physical or virtual learning environments, affinity spaces, virtual networks and professional online learning communities (Jobe et al 2014; Gee and Hayes 2012). The value of these communities of practice, as effective places for self-organised learning provides the potential for STEM educators to work collegially to morph existing STEM knowledge via the development of virtual collaborative learning networks and learning spaces. These can then be used as a mechanism to share and subsequently shape new STEM teaching and learning pedagogical principles, and to engage in interdisciplinary pedagogical discourse, with the aim of enhancing professional practice, in order to establish and develop disciplinary coherence through which new STEM knowledge and pedagogical best practice may be more readily shared.

From this perspective, rather than struggling to function within a structure that limits access to formal training, teachers have the agency to become leaders of learning and managers of change, working to influence and shape the direction of their subject. Teachers, however, need to be supported to access sustained and relevant academic professional development to help ensure they can develop appropriate technological pedagogical knowledge (Engelbrecht and Ankiewicz 2015). Teachers should develop their technology-enhanced practices, so that this activity may become standard practice, not only in order to enhance their own professional development, but also to gain skills they may utilise within their own practice to facilitate multi-literate delivery of 21st century skills.

Conclusion

This is a preliminary study, exploratory in nature, which the authors acknowledge is small scale. Findings do however provide a firm basis for further exploration of innovative ways to support teacher's professional learning. Building from this foundation, forthcoming work may involve undertaking a similar study in order to ascertain the perspectives, perceptions and experiences of teachers engaged in the delivery of the other STEM subject disciplines. Or to examine alternative innovative ways in which teachers may acquire, share and develop new and existing knowledge, and subsequently embed it within their own practice.

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