

The reality of STEM education, design and technology teachers' perceptions: a phenomenographic study

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Abstract The supply of highly qualified scientists, technologists, engineers and mathematicians is perceived by governments globally as being vital in securing economic prosperity, but somewhere along the line pupils are being 'switched off', and disengage with the study of science, technology, engineering and mathematics (STEM) beyond compulsory schooling. Improved STEM Education is presented as a way forward, and the supply of well qualified teachers is perceived as integral to achieving this vision. However in England and Wales, as government funded teacher training bursaries rise for those seeking to pursue a career in mathematics or science, funding for those wishing to train to teach engineering or design and technology is less lucrative. As individual disciplines both hold enormous potential to contribute to the STEM agenda, however currently this is not wholly realised. Set against a background of policy reform and curriculum change, this paper seeks to explore the ways teachers of design and technology perceive STEM, and how the range in variation of perception, relates to design and technology pedagogy. Phenomenography is the adopted methodology, and as such this paper explores participant's pedagogical understanding and perceptions from a non-dualistic ontological stance. The primary research tool was interview, which following data analysis, categories of description were formed to create empirically grounded outcome spaces. Outcomes from this study show that teacher's perception of STEM, their personal knowledge, and understanding of that knowledge, is intrinsically linked to the effectiveness of STEM delivery in their own classroom practice. In conclusion, findings from this study would support, in order for learners (pupils) to become STEM literate, that teachers of all STEM subjects be supported to explore ways in which they can best foster mutually reciprocal arrangements with their STEM counterparts.

Keywords STEM education · Design and technology · Phenomenography · Teacher perceptions

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Introduction

Originating as a government initiative in the USA (Kimbell 2011) the teaching and learning of Science, Technology, Engineering and Mathematics, which when considered collectively is known as STEM, is an area high on the agenda of governments globally. The increased supply of highly qualified scientists, technologists, engineers and mathematicians is perceived as being vital in securing the future of a nation's increasing economic productivity, prosperity, security and social well-being (Li 2014; Marginson et al. 2013; Obama 2013a; Katsomitros 2013; Roberts 2002).

However if calculations and predictions become reality (Stevenson 2014; BRT 2014a; Australian Industry Group 2012; ERT 2009) an insufficient number of young people are either equipped to study, or decide not to follow STEM based education programmes (Henriksen et al. 2014; ACT 2013; THE 2013; Hutchinson and Bentley 2011). Coupled with worrying rates of attrition for those embarking upon STEM based courses (Chen 2013) this projected lack of capacity points to an inability to deliver sufficient numbers of graduates, equipped to undertake STEM based occupations.

This potential crisis in capacity leads to an issue of significant concern for policy makers across the globe (Office of the Chief Scientist 2013; Kuenzi 2008; Lord Sainsbury of Turville 2007).

What is 'STEM'?

Everybody who knows what it means knows what it means, and everybody else doesn't.
Angier (2010)

In its simplest terms STEM is an acronym which describes the study of science, technology, engineering, and mathematics (STEM), a term whose original derivation is accredited to Judith Ramaley (Christenson 2011; Koonce et al. 2011).

The perceived importance of STEM as individual subjects key to a nation's long-term economic viability is not new (Bruce-Davis et al. 2014; Kelly 2012), nor is the concept of collaboration between the disciplines (Banks and Barlex 2014; Bybee 2013). Ramely (2011) described her vision for the term STEM; where she sought to develop a coherent, not integrated, curriculum, where science and mathematics served as 'bookends' for technology and engineering. However as a concept this has not translated fully into practice. Following the acronyms adoption, no single, universal definition exists, and depending upon ones individual's perspective or a prescribed context, STEM holds different meanings to different people (Capraro et al. 2013; Roberts 2013; Brown et al. 2012; Koonce et al. 2011).

Definitions are offered (Albrecht and Gomez 2014; Dugger 2010, 2014), although few agree with one when it is presented (Bybee 2013), suffice to say that STEM is a ubiquitous and ambiguous '*slogan*' (Bybee 2013), opaque and confusing (Angier 2010) even to those who employ it (Sanders 2009).

Addressing STEM through education

For over a decade STEM has been a topic of international discussion. A discussion driven by the challenges of a changing global economy, fuelled by indications of an impending

global shortage of STEM based workers (Ritz and Fan 2014; Kennedy and Odell 2014) not lessened by growing concern around the ‘disconnect’ between students who say they plan to pursue STEM careers, and those who demonstrate a real interest in the STEM based disciplines (Heitin 2014).

One way governments are working to meet the emergent challenges is through education, and the process of STEM educational reform (Banks and Barlex 2014).

Numerous projects are being undertaken to explore the development of innovative STEM focused activity in order to determine the best ways to deliver individual STEM subject disciplines (ESRC 2014; Clark 2013; Capraro et al. 2013).

However, as has occurred elsewhere (Benken and Stevenson 2014; Kelly 2010; Cavanagh and Trotter 2008), in the United Kingdom (UK) policy is unequal and frequently negates to consider the importance of technology and engineering’s fundamental role in STEM education, focussing primarily only upon mathematics and science as this quotation illustrates;

...to raise the status of STEM subjects, and increase the number of students studying maths and physics at A level by 50 per cent within 3 years.

The Rt Hon Nicky Morgan MP (2014)

In the context of education, if we are to capitalise fully upon the potential that an integrated STEM curriculum holds, collaboration and to some extent, integration must be sought.

The drive to realise the benefits of interdisciplinary collaboration is not new (Gloeckner 1991) however more often than not a silo approach to the delivery of individual STEM subjects has been adopted, with little attempt at integration (Katehi et al. 2009). To support the delivery of a curriculum that goes beyond the individual content of the four subject disciplines Banks and Barlex (2014) promote ‘*looking sideways*’, whilst seeking to realise the potential of ‘*true*’ STEM education Gomez and Albrecht (2013) advocate an interdisciplinary approach rooted in STEM pedagogy. The latter enables students to become more aware of real-world connections, and through this relevance will become further motivated to engage students. Delivery should be focused on learning to do something with knowledge acquired (Moye et al. 2014; Honey et al. 2014), an idea shared by Capraro et al. (2013) who advocate the adoption of a problem-based learning approach.

Moving from the acquisition of facts to the investigation of the practical application of principles and theories, seeking to create purposeful learning environments, will enable students to understand contexts in which they can be applied and in so doing they will become STEM literate.

Addressing STEM through effective teacher supply

We need to make this a priority to train an army of new teachers in these subject areas, and to make sure that all of us as a country are lifting up these subjects for the respect that they deserve.

President Barack Obama, Third Annual White House Science Fair (2013b)

A second strategy deemed central in further securing the aim of a world class STEM workforce is the supply of well-motivated, highly qualified STEM teachers (Kuenzi 2008; Bassett et al. 2010), a strategy echoed in the UK:

The Review recommends a major campaign to address the STEM issues in schools. This will raise the numbers of qualified STEM teachers by introducing ... financial incentives.

Lord Sainsbury of Turville (2007)

However, similarly to other aspects of UK STEM policy, whilst there have been increases in bursary funding for those embarking upon STEM initial teacher training (ITT) there is significant variance depending upon the subject discipline.

For those holding a first class degree and seeking to pursue a career as a teacher of mathematics, physics, chemistry, and computing a training bursary of £25,000 is available (Department for Education 2015a), and bursary payments for undergraduate students training to teach mathematics and physics were announced in January 2015 (Department for Education 2015b). However support for those training to teach engineering or Design and Technology (D&T) is less lucrative. Having previously been classified as a shortage subject, bursaries for postgraduate D&T trainees were cut in 2011, and have only recently been reinstated (September 2014). Currently there is a £12,000 bursary available for those holding a first class honours degree, however for those following an undergraduate route, or seeking to pursue an engineering ITT qualification there is no bursary entitlement. Understandably this financial inequity has the potential to lead to a reduction in the number of candidates training to teach these STEM subjects, an inconsistency which is perplexing, as both engineering and D&T are STEM disciplines and both have much to offer STEM education.

D&T; valued as a STEM discipline?

As a curriculum area D&T was introduced as a result of the 1988 Education reform Act. Under the terms of reference made to the working group, D&T was defined as a subject:

...in which pupils design and make useful objects or systems, thus developing their ability to solve practical problems.

Department for Education and Schools (1988)

The remit was clear in defining a context for how this new subject would operate and documents highlighted the curriculum allegiances that it should consider;

The working group should assume that pupils will draw on knowledge and skills from a range of subject areas, but always involving science or mathematics.

Department for Education and Schools (1988)

When delivered effectively, D&T enables children to understand, through practical application, theoretical aspects of science and mathematics and it is upon these principles that the subject was first conceived.

However as a national curriculum subject in England and Wales D&T has been persistently marginalised and despite being one of the country's most popular General Certificate of Secondary Education subjects, and the "*only place in the curriculum where practical problem-solving takes place*" (Green 2014), coinciding with a fall in the number of teachers qualified to deliver the subject, there has been a decrease in pupil numbers with just over 230,000 taking the GCSE D&T qualification currently, compared to around 450,000 ten years ago (Green 2014).

In 2008 Barlex noted that in relation to STEM education, the position of D&T had “*oscillated between insignificance to [that of] valued contributor*” for some time.

However in practice since 2008 there has been no oscillation and the impact of policy in practice reinforces fears that “*without intervention from ministers [D&T] may even cease to exist within five years*” (Green 2014) which understandably has created apprehension among many teachers of D&T.

Given the status of D&T within the curriculum, increased alignment with STEM education may potentially offer a life line, with some arguing for an integrated STEM curriculum (Hardy et al. 2008), whilst others resist, fearing the loss of D&T’s individual identity as a subject in its own right (Williams 2011). Unsurprisingly this situation has created pockets of conflict with a number of D&T teachers reluctant to explicitly engage in STEM education.

Focussed within the context of STEM education, the study presented here engages with the ongoing debate surrounding D&T’s value, purpose and place (Williams et al. 2015; Owen-Jackson 2013; de Vries 2011) within a school based curriculum and seeks to explore the views, perspectives and opinions of D&T teachers in relation to their pedagogical understanding and perceptions of STEM. The work undertaken specifically seeks to investigate the following:

- In what ways do D&T teachers perceive STEM?
- How does the range in variation of their perception relate to D&T (secondary) pedagogy?

Methodology

Phenomenography is the methodological approach adopted here, which, according to Åkerlind (2005), emerged from an empirical background, as opposed to a theoretical or philosophical one, and may be defined as the empirical study of ways in which various phenomena are experienced, conceptualised and understood (Marton 1994).

‘*Reality is a human construct*’ (Wellington 2000) and from this perspective there is no single view of the world, a real world ‘*out there*’ and a subjective one ‘*in here*’ (Marton and Booth 1997) which according to Marton (2000) leads to a non-dualistic ontological approach. From this perspective, STEM is understood to be a human construct, rather than as a ‘fixed’ body of knowledge and, therefore, is subjective and open to constant interpretation, construction and reconstruction by the individual; knowledge is constructed and in light of experience and understanding modified within the mind (Vygotksy 1978).

As an approach phenomenography seeks only to describe a phenomenon, and not to explain, justify, understand or assign meaning to it.

Irrespective of the phenomenon being explored there are a limited number of ways in which a phenomenon can be experienced (Marton 1994). According to Marton and Säljö (1997), phenomenography is a process more of discovery than of verification, with the purpose being to highlight variation in the collective and in doing so present alternative views rather than focussing upon the individual experience (Åkerlind 2005).

Data collection

Within phenomenography a single figure sample size can be as valid as a large one (Bruce et al. 2004; Trigwell 2000), and it is a common misconception that an increase in sample

size will lead either to results that are statistically reliable or an increased number of conceptions and outcome spaces. Trigwell (2000) advocates a sample size of between 10 and 20 participants and in this study nineteen participants were selected.

Participants were selected in order to encompass as wide a range of demographic variation as possible, however each met the following criteria;

- All were qualified teachers i.e.: holding Qualified Teacher Status.
- All were working in the mainstream secondary sector in England and Wales.
- All were teaching D&T (National Curriculum)

In relation to D&T, participants held expertise in the following areas; catering, hospitality, food technology, child development, product design, resistant materials, electronics, systems and control, textiles, graphic products, engineering and motor vehicle maintenance. Of the participants three taught one area of D&T, with nine engaged in delivering four areas or more. Three also reported teaching areas considered to be outside of the usual D&T curriculum including subjects such as; mathematics, science, computer science and information technology, art, citizenship, Personal Social Health Education, and Religious Education.

The gender breakdown of the research sample was almost equal with ten female and nine male participants, their ages ranged between twenty-eight and sixty-two years old. Years in service (teaching within secondary education) ranged from one to thirty-nine and all participants were working within their respective institutions on a full time basis.

A number of participants held additional responsibilities within their institutions including; departmental, pastoral and whole school leadership and advanced skills teacher status. Four collaboratively ran a STEM club, and two were the school's STEM co-ordinator. At the time of the study six schools were designated technology or engineering college's, and following their respective Ofsted inspections one was classified as being in 'special measures' and another as being given 'notice to improve'.

A series of semi-structured face to face interviews, conducted using procedures advocated by Kvale (1996) and Bowden and Green (2005), were used as the primary research tool to gather empirically grounded data relating to the perceptions, understanding, and 'lived experiences'. In phenomenographic research the interview is crucial (Willmet 2002) and in this study questions were designed to encourage participants to lead conversation, enabling them to reflect upon their experience, knowledge and conceptual understanding in an open way. A neutral setting was used, and interviews held at a time convenient to the interviewee.

Interviews were conducted by a single researcher, 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, and all research was conducted in accordance with the ethical guidance described by British Educational Research Association (BERA 2011). Informed consent was obtained from all participants, and an assurance was given that dialogue would remain confidential and identities concealed to assure anonymity of themselves and their settings.

In each interview participants were asked to talk about their favourite D&T project, one with which they were comfortable, had confidence in delivering and that they enjoyed teaching. As the conversation developed participants were encouraged to articulate the skills, knowledge and understanding which was embedded within that project. Supplemental questions were asked as prompts if the natural flow of conversation began to cease. In order to elicit rich, detailed descriptions further questions sought to ask 'why?' rather than 'what?' (Åkerlind 2005). Participants were asked: 'Why do you think this is a good project?' or 'Why are you teaching it like that?' Dialogue encouraged discussion around how the project described linked to others areas of D&T and those across the curriculum.

Only as conversation drew to a close was a question, gauged to establish their awareness of STEM, posed, and depending upon the interviewee's response the interview was either brought to an end, or its continuance enabled.

Typically interviews lasted for a period of between forty-five and sixty-five minutes. Each was recorded and transcribed verbatim. To avoid ambiguity, following transcription, participants were asked to verify their individual accounts in order to ensure that their perceptions of the phenomena had been accurately captured. Transcripts were then anonymised and subsequently analysed.

Data analysis

Analysis was conducted in accordance with procedures advocated by Marton and Booth (1997), Åkerlind (2005) and Ashwin (2005). Transcripts were examined in order to identify similarities and differences between the way in which participants experienced STEM, and relationships between emerging patterns and themes identified.

Strategies vary between phenomenographers in relation to the analysis of interview transcripts. Prosser and Trigwell (1993) prefer to explore transcript segments, whereas Svensson and Theman (1983) conduct the process through analysis of smaller sections and quotations. The approach taken in this study was to consider the interview transcripts as a whole as advocated by Bowden and Walsh (2000).

In order to identify interrelated themes a simple coding system was used to illuminate similarities and differences. Excerpts with meaning were extracted, coded and then revisited in order to check the context in relation to the meaning of the excerpts. Where similar word or sentence responses occurred, excerpts that exemplified the differences in variation and meaning were then collated. In accordance with established technique as advocated by Barnacle (2005) transcripts were re-analysed with care being taken to avoid misrepresenting the given meaning assigned, this involved an iterative approach, checking interpretations and continually sorting and comparing the data, until saturation was deemed to have occurred.

Data was then treated as a single transcript and used to produce "*conceptions from a pool of meanings*" (Åkerlind 2005), analysis then focused upon the identification of the qualitative differences in variation for the purposes of establishing categories of description, with the 'space' in between each providing the variation of importance. Through this process key elements that are similar in perception (Cherry 2005) are aggregated (Barnacle 2005) to form categories where conceptions move beyond the individual perception (Green 2005) and ascertain the variation of the group, this is the process undertaken in this study.

Criticism of phenomenography (Sandbergh 1997; Webb 1997) focuses on the researcher's ability to set aside their own preconceived ideas; because what we experience is our reality, and our 'natural attitude' is to assume that 'our' world view is identical to the world experienced by others (Fazey and Marton 2002). As phenomenography seeks to identify multiple perspectives held by members of a particular group in relation to the same phenomenon, it is vital that the researcher understands that different people may experience the same 'thing' in different ways.

Prosser (2000) makes reference to the difficulty of setting aside one's own assumptions and pre-conceptions. To help avoid bias at this stage of the research, and ensure that a second order perspective was maintained, the strategy of '*bracketing*' (Bruce et al. 2004; Ashworth and Lucas 2000; Dunkin 2000) was adopted.

Following analysis of the data categories of description were formed to create four empirically grounded outcome spaces.

Results: the creation of outcome spaces

Within phenomenography the difference between the ways that a group of people experience the same phenomena can be referred to as ‘conceptions’ (Marton 1981). Conceptions are organised into ‘categories of description’ which are then used to create a hierarchical set of understandings which are referred to as an ‘outcome space’ (Marton 1994), although a hierarchical structure is not essential (Green, 2005). Categories are determined by the researcher’s analysis of the individuals’ accounts of their lived experience of the phenomenon and in creating outcome spaces Marton and Booth (1997) suggest adherence to three criteria:

- Categories should reveal a different and distinct component of the phenomenon.
- Categories should be logically related, and be hierarchically in relationship to each other.
- Categories that describe variation across the sample (outcome spaces) should be as few in number as possible.

As a research tool, phenomenography seeks only to ascertain the differences in variation, and it does not attempt to understand why participants think or conceive the same phenomena in a different way (Cherry 2005). Categories should not be perceived as aligning with an individual, nor is it expected that participants should ‘move up’ through categories (Trigwell 2006).

In addressing the question; *in what ways do D&T teachers perceive STEM?* Evidence emerged to support the construction of four qualitatively different ways (categories of description) that teachers participating in this study understand and perceive STEM, these are illustrated in Table 1.

Category 1 is limited to externally imposed knowledge. That is to say where there is an awareness, as a concept STEM is imposed upon them. The qualitative difference between categories 1 and 2 is internalisation. In category 2 internal engagement with knowledge occurs. There is evidence of surface knowledge, but understanding is deficit and in practice it is re-presented to others through a process of regurgitation. The qualitative difference between category 2 and category 3 is understanding. Category 3 is defined as internal engagement with evidence of knowledge transfer into understanding. The qualitative difference between category 3 and category 4 is the depth of understanding. Category 4 deals with internal knowledge which is fully analysed and synthesised, where full understanding is evident.

Category of description 1: STEM knowledge learned from external relationship: STEM as an externally imposed concept, where there is an awareness knowledge is limited and emotionally evokes feelings of apathy, fear, and apprehension.

Extracts of interview statements aligned with category 1 define STEM as an externally imposed concept. In this category there may be no awareness:

I don’t know what that [STEM] is, sorry.

Interview 17, Extract 24

Table 1 Categories of description

1	STEM knowledge learned from external relationship: <i>STEM as an externally imposed concept, where there is an awareness knowledge is limited and emotionally evokes feelings of apathy, fear, and apprehension</i>
2	STEM knowledge learned from internal relationship: <i>STEM as surface knowledge, deficit in understanding, but demonstrating an internally imposed desire to acquire new learning</i>
3	STEM understanding learned from internal relationship: <i>STEM as personal development, evidence of a growing confidence to confront their own understanding and to acquire and apply new knowledge</i>
4	STEM understanding taught through internal relationship: <i>Pragmatic approach to the delivery of STEM, displays complete understanding</i>

Where there is cognisance, in category 1 externally imposed knowledge is limited, and emotionally this category evokes feelings of apathy, fear, and/or apprehension:

I'm not completely sure what STEM is to be honest. I was asked if I'd like to get involved running a club, but it's more to do with maths and science... Maths isn't my strong point so I'd probably show myself up [in front of the pupils].

Interview 3, Extract 4

Category of description 2: STEM knowledge learned from internal relationship: STEM as surface knowledge, deficit in understanding, but demonstrating an internally imposed desire to acquire new learning.

The qualitative difference between categories 1 and 2 is internalisation. In category 2 knowledge is internalised but is shown as surface knowledge with no evidence of understanding. There is an awareness of STEM that can be explained through descriptive (although not always accurately) paraphrasing and reporting:

STEM? Yeah...I've heard of it... Science, Technology, English and Maths isn't it?

Interview 8, Extract 19

Responses presented a deficit in terms of understanding, but there is evidence of an internal struggle with surface knowledge:

I'm involved, but I'm not at all sure what I'm doing. I don't know [understand] enough at the moment... but I'm keen to learn...so I can help the kids.

Interview 1, Extract 14

Category of Description 3: STEM understanding learned from internal relationship: STEM as personal development, evidence of a growing confidence to confront their own understanding and to acquire and apply new knowledge.

The difference between category 2 and category 3 is understanding. In category 3 there is evidence of movement from basic knowledge acquisition, through an internal process of reflection into understanding. Within category 3 there is evidence of a knowledge application evolving into deeper understanding which results in knowledge and concepts being applied to, and explored in, new situations. There is an acceptance that as a concept STEM is difficult to define:

I don't think that anyone really knows quite what STEM is, if you ask someone from maths or science or another school they will give you a different answer to me...

Interview 11, Extract 24

Respondents display an emergent confidence and there is a commitment to personal growth, learning and development:

If I don't know how to do something I go and find out... sometimes I think I learn as much as the pupils!.

Interview 11, Extract 16

I try to build STEM into my lessons, it's just a case of giving a go...how can I teach the kids to take risks if I'm not prepared to do it myself?...were all learning all of the time.

Interview 10, Extract 27

Category of Description 4: STEM understanding taught through internal relationship: Pragmatic approach to the delivery of STEM, displays complete understanding.

The qualitative different between category 3 and category 4 is the depth of understanding. Within this category internalisation and reflection goes beyond basic understanding, there is evidence of deep analytical analysis and synthesis of STEM as a concept. In most instances this leads to reflection in action as STEM is applied in practice to develop themselves and their pupils through applied pedagogy:

They make their own design decisions and I let them experiment with the materials so they decide which they should use and they tell me why.... all of my lessons have STEM ... however we do not formally identify this in our schemes of work or tell students this is STEM.

Interview 2, Extract 10

A HMI watching a boy ... turn a piece of steel using the scale on the cross slide to calculate how much the diameter of the bar had been reduced by... passed the comment that she thought it fantastic that the children were using maths so readily without thinking about it... Maths, science, engineering are all interrelated. A car is just a physics lesson that drives along the road! D&T is STEM in action!

Interview 14, Extract 6

However also falling within this category are those who display deep understandings of STEM, but choose to distance themselves from engaging with the STEM agenda:

I ran tech club for years with no money and we did all sorts of things... and entered a couple of competitions ...then all of sudden the science department got [all sorts] funding, not only to run a club, but to send some of the staff on 'training'. The only time anyone seems to want me to be involved is when they want something, but my department doesn't get any capitation and they [science] take all of the credit.

Interview 5, Extract 18

The identification of referential and structural relationships

The perceptions of STEM held by teachers influence the way that they, as learners, develop their understanding of STEM. It is plausible therefore to suggest that this in turn will impact upon the way they teach STEM.

Having established the outcome spaces, according to Bowden and Walsh (2000) further analysis (of the categories) can lead to emergence of additional component parts which sit within the constructed conceptions. This process creates an additional dimension, and helps give overall meaning to different aspects of the phenomenon (Harris 2011). These are known as structural and referential dimensions, or the 'how' and the 'what' (Marton and Booth 1997), with the structural component representing the internal and external horizons of the phenomenon, and the referential component attributing meaning to the experience (Pang 2003).

Through analysis of the structural and referential composition of experiences, as described by each participant group, in accordance with the approach adopted by Marton and Pong (2005), analysis of these categories of description led to further organisation of the outcome spaces to explore the second research question; *how does the range in variation of this perception relate to D&T (secondary) pedagogy?*

Table 2 illustrates how an outcome space can be described in terms of its referential and structural aspects. The structural elements refer to how knowledge and understanding was described, whilst the referential element refers to how the D&T teacher's perceptions of STEM (internally and externally) would be learned and taught (applied pedagogically).

Pedagogical conception 1

STEM knowledge learned from external relationship: described

In relating this conception to pedagogical practice, where the teacher has no understanding of STEM consequently the referential element, where STEM is applied through practice, pedagogy is limited.

Where the teacher has an awareness, but knowledge is external imposed they are disassociated from STEM and pedagogically STEM is delivered in a dualistic way, which may manifest itself as a set of externally imposed facts, to be memorised (described) rather than explained and learnt and applied for any real purpose:

... Then they copy out basic maths formulae, Ohms law, resistors in series etc..

Interview 18, Extract 8

STEM Knowledge is disassociated from the work pupils undertake and STEM has no applied purpose. The adoption of a dualistic approach to STEM limits the potential of the learner, applying to both the teacher, and the pupils. Within pedagogical conception 1 the teacher (or pupil) may be able to produce (know) the right answer, but they have little or no understanding of how or why it is correct. For the child there is little or no understanding of why they are undertaking the set task.

Pedagogical conception 2

STEM knowledge learned from internal relationship: explained

In pedagogical conception 2 practice follows a dualist approach, which present itself as a surface approach to learning. The teacher is able to transfer STEM knowledge to learners through explanation, showing or telling, but their own understanding of that knowledge is deficient. As a result the teacher lacks confidence, there is no opportunity for pupils to

Table 2 Pedagogical Conceptions of Teaching STEM

Structural	Referential (STEM applied pedagogically)			
	Knowledge	1	2	
	Understanding		3	4
	Described External relationship learning STEM	Explained/Applied Internal relationship learning STEM	Analysed/Synthesised Internal relationship teaching STEM	

engage in mistake making, or risk taking, and the limitation in the teachers understanding frequently manifests itself in identical whole class project outcomes:

I demonstrate the task and then tell the pupils get to do it themselves, then when everyone is ready we move onto the next stage [step] of the process....

Interview 19, Extract 7

...First of all I explain what we are going to do that lesson and then I show them [the pupils] what to do...so in this project all students get to work on a pre-designed board... then once that is finished I show them the next step and they go onto make the casing...

Interview 4, Extract 7

The teacher explains and learners receive a set of instructions to follow, reliant on the teacher for the next step. Within D&T learning becomes product focused, there is little scope for individual pupil creativity. As a result learning by the pupil is limited to the imitation of a series of physical operations. In measuring progress [marking] is atomistic and formulaic, and success of the task is measured, by both teacher and pupil, in terms of a complete product.

Pedagogical conception 3

STEM understanding learned from internal relationship: applied

Within this conception teachers begin to challenge their own knowledge and understanding of STEM. They are at the early stages of beginning to be able to socially re-construct their understanding of STEM, apply it and pedagogically growing in their ability to support pupils in their own learning to be able to make meaning from the knowledge and skills.

They are able to illustrate through the identification of emergent connections and relationships examples of how STEM can be delivered when linked to their own teaching of D&T. Typically when describing teaching language, they utilise terminology such as; design, create, modify, solve, construct and discover.

Opportunities for problem solving and some independent work is provided, there is less focus on the final outcome and more on the learning journey:

... the pupils are really creative ... they show the development of their skills... basically everyone starts off making the same thing but ... the outcomes are very different, I encourage them to use the same skills in different ways and think about the skill that is best.

Interview 6, Extract 2

Holistic marking is in place for some aspects of the task but the marking of work reflects the learning that has taken place, and is not measured solely upon outcome. This illustrates a growing confidence by the teacher in their own ability to measure something other than recollection of knowledge by the pupil. It is a move toward a non-dualistic perception of STEM education:

It's more of a challenge to deliver ... but it makes the children learn more by getting them to think... it's harder to mark this kind of project because ... team work and problem solving aren't things you can't easily give a grade for.

Interview 15, Extract 5

Pedagogical conception 4

STEM understanding taught through internal relationship: analysed and synthesised

The difference between conception 3 and 4 is the understanding of STEM, coupled with the ability to translate that confidence in the classroom to those they teach through pedagogical application.

Pedagogical practice goes beyond demonstration, and actively encourages thinking, doing and risk taking within an active learning environment. Knowledge, and understanding of that knowledge is confidently applied:

I facilitate the work by starting with a broad problem and then support them as they begin to design and formulate their own solutions.

Interview 14, Extract 3

The teacher understands STEM from a non-dualistic perspective. Learning encourages pupils to make STEM connections through active engagement, deep learning is encouraged and facilitated. From a non-dualistic approach to STEM, when perceived as a human construct, STEM has been created in order to aid understanding. This approach encourages the social construction of both the teacher and the childgap from an international's own learning. Confident teachers display a pragmatic approach to the delivery of STEM, and understand the wider relevance as being essential, knowledge and understanding is demonstrated with a fluid articulation of how almost any task or operation within D&T, and other curriculum areas, contain STEM.

The focus is always on the learner, and frequently it manifests itself through work undertaken outside of the taught curriculum, through clubs, competitions, extra-curricular and cross curricular work. Marking is wholly holistic. When describing an applied task typical language used in this category to reflect experience included terminology such as; facilitated, supported, created, formulated and communicated.

Even where a teacher resists engagement with the development of STEM education, there is an acknowledgement that it is almost impossible to deliver D&T without addressing some aspect of STEM. In this conception teachers cite full and in-depth examples easily and confidently. This confidence results in the undertaking of pedagogical tasks and activities that encourage risk taking, and lead to real problem solving:

...it's what D&T is all about... they learn the facts in maths and science but when they come to us that's when the real learning takes place. Until you begin to actually apply knowledge, justify your decisions and put it into practice what you have learnt you haven't got a clue. Only when they (the children) can see a purpose in what they have learned, and how it can be applied do they really begin to understand.

Interview 16, Extract 16

Conclusions and implications for the teaching and learning of STEM

Findings from this study show that the teacher's perception of STEM, their personal knowledge, and understanding of that knowledge, is intrinsically linked to the effectiveness of STEM delivery their own classroom practice. Where a teacher's own knowledge and understanding is deficient, findings indicate the potential for pupil learning is limited.

The variance in perception, highlighted in this study, suggests that some D&T teachers have a limited understanding of STEM, and as such they are consequently unsure of the contributions that they can offer. This would suggest a need for additional support at the chalk face, however against a background of policy that continually places less value on D&T as a subject within its own right (Green 2014); excluded from access to the highest (STEM focussed) ITT bursary's (Department for Education 2015a, b) and with STEM initiatives and funding persistently focusing only on science and mathematics (Morgan 2014; ESRC 2014), obviously some D&T teachers are unsure if STEM falls within their area of responsibility, whilst others, who seek to be involved, feel excluded.

Unsurprisingly tensions arise in relation to the delivery of STEM, and these findings show, sadly that little has changed in the 5 years since Barlex (2009) revisited earlier studies (Barlex and Pitt 2000; Lewis et al. 2007), which highlighted misunderstandings between science and D&T teachers perception of each other's subject, which in turn led to antagonism and subsequently a failure to develop cross-curricular activities.

In teaching, how something is learnt can be as important as what is being taught. STEM subjects are vibrant, engaging and exciting, but somewhere along the line pupils are being 'switched off' in their droves, and disengage with study beyond compulsory schooling.

Projections indicate that insufficient number of young people are choosing to study STEM based subjects (Chen 2013; ACT 2013) and given the international significance of STEM, and the desire by governments globally to secure an effective STEM based workforce (Bell et al. 2014; BRT 2014b; Fan and Ritz 2014; Obama 2013a; Katsomitros 2013), if education is indeed the solution, then something different needs to be done.

Clearly, D&T has much to offer STEM education, and it presents opportunities for 'doing' based activities (Moye et al. 2014), where pupils are engaged in practical problem solving, and as such is a logical subject areas through which to deliver 'True STEM education' (Gomez and Albrecht 2013), however there is a persistent failure to recognise the value of this potential.

In practice inequity in policy expedites the continued silo nature of the STEM subjects, making it difficult to capitalise on opportunities for a combined curriculum. However this is not to suggest that findings from this study would advocate a prescribed, and integrated STEM programme, as the introduction of a dualistic curriculum could be counter-productive, and would, potentially hinder exemplar work already being undertaken.

Reeve (2015) advocates teachers as 'STEM Thinkers', actively promoting the concept of STEM to their students who, through this approach, will begin to appreciate how STEM

disciplines interconnect and in turn realise the impact the integration of STEM subjects has on society.

Findings from this study would support, in order for learners (pupils) to become STEM literate, that teachers of STEM subjects be supported to explore ways in which they can best foster mutually reciprocal arrangements with their STEM counterparts leading to the creation of an interdependent, cooperative and symbiotic curriculum.

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