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The effect of teacher's confidence on technology and engineering curriculum provision

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Abstract

Secondary school, age range 11–14, technology and engineering education in England has been delivered mainly within Design and Technology (D&T). This inadvertently makes D&T teachers responsible for pupils' engineering education and motivation. This paper analyses D&T teachers' (N = 33) technology subject knowledge through self-assessment competency questionnaires, before and after developing a Science, Technology, Engineering and Mathematics (STEM)-focused project of their choice for their classroom. Participants were least confident in teaching the areas of technology that required mathematics and scientific knowledge. The results analyse a suggested misalignment between teachers' Creative Arts background subject knowledge compared to the technology subject knowledge required for engineering education. Suggested causes of this issue are Initial Teacher Training standards and curriculum flexibility, not teacher capability. The paper concludes that teachers have been unaware of some elements of STEM education and that continuing professional development interventions are required to assist teachers and improve their engineering knowledge in order to better equip their pupils for engineering.

Keywords STEM education · Initial teacher training · Subject knowledge · Design and technology · Competence

Introduction

The grouped movement of Science, Technology, Engineering and Mathematics (STEM) education is vital to the UK. In particular, for the scope of this paper, in England due to the continued demand for, and a shortfall of, the supply of engineering technicians and graduates to the workforce (Atkins 2015; Neave et al. 2018). Within the compulsory curriculum, for pupils aged 5 to 14, the teaching of Mathematics and Science is clear and contained within individual subjects. Technology is spread across Design and Technology (D&T),

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and Information Technology (IT). Engineering is rarely taught as a distinct subject (Harrison 2011). The subject of D&T is therefore responsible for delivering the most substantial amount of technology and engineering content in the curriculum, as well as sharing design with Art & Design. D&T also has the purpose, from the National Curriculum (Department for Education 2013a), of applying the separate areas of STEM through design. This suggests that D&T has a uniquely important position in a pupil's education concerning STEM and exclusively to technology and engineering.

The motivation for this research to investigate D&T at the secondary school, 11–14 age range, is the yearly trend of decline in the number of pupils taking exams once the subject is optional at age 16 (Joint Council for Qualifications 2015) and 18 (Joint Council for Qualifications 2016). Prior research (Jones et al. 2018) has investigated pupils' cognitive and affective engagement in this subject, and this paper contributes to the body of knowledge on D&T teachers' at this age group.

In England, D&T teachers are uniquely required to be able to teach a broad range of topics that could be relevant to technology and engineering education. Since the introduction of Initial Teacher Training (ITT) standards (Department for Education and Skills & Teacher Training Agency 2003) the Design and Technology Association (2003) have produced complimentary subject minimum competence guidelines. The D&T Association's minimum competence statements were adopted and used by ITT providers in conjunction with the statutory requirements for D&T ITT. These define the Core competences of D&T and the competences of the four specialist fields of Electronics and Communications Technology, Food Technology, Materials Technology, and Textiles Technology at various levels of education. These subject-specific minimum competence statements were updated in 2010 (Design and Technology Association 2010).

There is flexibility in the training a D&T teacher in England receives, because of interpretation of the D&T Association minimum competences (Martin 2008), combined with the relaxation of a strict competence-based progression framework for all levels of teachers (Department for Education 2013b). It was identified that there are problems explicitly associated with the teaching of technology and engineering content within the subject. The key findings in D&T subject reports from the Office for Standards in Education, Children's Services and Skills (Ofsted 2008, 2011) were the lack of relevant expertise in secondary school D&T teachers for the broad range of technology content within D&T. These reports were based on evidence from Her Majesty's Inspectorate evaluations of the provision of D&T in schools. These findings suggest that the content of current teaching in D&T is limiting pupils' experience.

As teachers' technology expertise has been identified as an issue, it is necessary to identify the types of knowledge which teachers do have. Theoretical models of teachers' knowledge have been developed since the mid-1980 s. Many researchers have classified the domains of teacher knowledge in order to understand teachers' pedagogy (Banks 1996a; Banks et al. 1999; McNamara 1991; Mishra and Koehler 2006; Shulman 1986, 1987; Turner-Bisset 1999). These models are independent of any field of study. In all of these models, what is important for this body of work is the explicit separation of subject knowledge and pedagogic knowledge. Subject knowledge in all of the models it is the knowledge contained within and about a discipline. Pedagogic knowledge is an understanding of the tools, methods, theory and approaches used to educate that transcend the subject matter.

In ITT, prospective teachers develop their pedagogic knowledge to become excellent at teaching in preference to the development of subject knowledge. Limited development of subject knowledge takes place during ITT (Atkinson 2011; Banks 1997; Benson 2009) or during service (Micklewright et al. 2014; Ofsted 2011) resulting in the significant

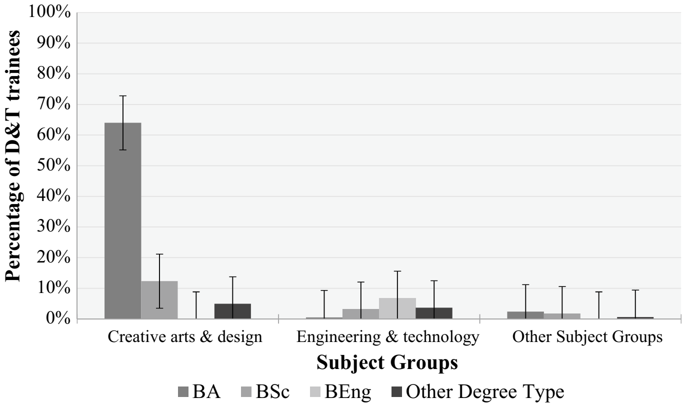

Fig. 1 Type of qualification held before D&T ITT (N = 341). Other Subject Groups includes architecture, building and planning, business and administrative studies, agriculture and related subjects, librarianship and information science and physical sciences. Other degree types include City and Guilds of London Institute (CGLI), Higher National Certificate (HNC), Higher National Diploma (HND), Bachelor of Design (BDes), Master of Arts (MA), Master of Design (MDes), Master of Engineering (MEng)

importance placed on the subject knowledge possessed by the teacher prior to training and entry into the teaching profession.

Jones et al. (2014) used the distribution of first degrees, as an indicator of prior subject knowledge, for teachers who undertook their ITT on the Loughborough University D&T PGCE programme between 2000 and 2013, see Fig. 1. Most trainees, 66% (n = 226, 95% CI [57.56%, 75.22%]), held a Bachelor of Arts (BA) degree in a creative arts and design subject. The percentage of trainees with qualifications in engineering and technology subjects was only 14% (n = 48, 95% CI [5.25%, 22.91%]). Lewis (1995) recognises that there is more than one factor other than prior qualifications to assess the alignment of a trainee to their ITT programme and that other experience would make them suitable.

The PGCE programme studied by Jones et al. (2014) consistently produced qualified teachers in-line with all the statutory requirements and was consistently rated outstanding in consecutive inspection up to its most recent and final inspection (Mann and Ofsted 2011). It closely followed the guidance of the D&T Association Minimum Competences for Trainees to Teach Design and Technology in Secondary Schools (Design and Technology Association 2010). These competence statements cover both design and technology subject knowledge development

A concern is that the broadness and level of technology or technical skills development in a BA design subject is considered to be less than a Bachelor of Science (BSc) or Bachelor of Engineering (BEng) in engineering (Quality Assurance Agency for Higher Education 2015, 2017). For example, it would not be expected for an Arts student to know non-parametric CAD and CAM, mechanics, systems, electronics or many of the other high-technology level areas of the D&T curriculum. If this majority of D&T teachers with a Creative Arts and Design background do not have the technology subject knowledge, then it is suggested that this could be a limiting factor to the amount of technology content taught in secondary schools.

While the scope of this paper focuses on the context and results from only the English secondary school system, other international stakeholders will find the work relevant. For example, Australia, Canada, New Zealand, South Africa, USA and the UK nation states all have an equivalent of the English D&T subject (Jones 2009). The impact extends beyond secondary school, as school level technology education is an essential influence in post-school technological studies and professions (de Vries 2009).

This paper aims to investigate English secondary school D&T teachers' subject knowledge related to the externally imposed requirements for technology and engineering education. Misalignment of these factors could contribute to obstacles experienced by teachers in developing and delivering technology education in secondary schools. This paper investigates the effects of any misalignment through the following research question: To what extent does D&T teachers' subject knowledge prepare for, and align to technology curriculum provision?

Method

Overall project and resources provided to schools

This paper presents findings of research collecting teacher metrics recorded as part of the 2015 programme 'Enhancing the teaching of STEM through Design and Technology (Mindsets STEM Enhancement Project)' (Mitchell et al. 2015). This programme was created and managed by the Design and Technology Association. It provided schools with free technology project resources intended to make technology education more engaging. This paper presents only the findings of teacher's self-assessment of teaching confidence about the schemes of work created during this programme. The authors of this paper did not design any projects or resources for teachers nor guide them in what they should do in class.

The focus of the programme was to give teachers, in their schools, one academic year (2014/2015) to implement a new STEM project of their subject and during a chosen period, using provided Mindsets STEM materials, components and equipment. STEM in this context refers to the application of any individual STEM subject element into D&T education. Example projects, used by many schools, from this range of resources were materials investigation tutorials and LED balancing lamp kits. These provided sample materials for pupils to experimentally investigate their properties and potential design applications, and resources to mathematically design a counterbalanced lamp as an introduction to electronics, respectively.[1] This paper, therefore, presents findings related to technology subject matter teaching from teachers who are developing their new STEM projects.

Participating schools were divided into two groups; the location and names of schools have been kept anonymous to maintain confidentiality. Initially, four specifically targeted schools, geographically spread across London, were involved in acting as examples and aiding communication between schools. The second group was formed by the advertisement of the project and the self-registration of 92 other secondary schools across London. This study only investigated schools across London as it was funded by the London Schools Excellence Fund. This geographic limitation is not expected to have a significant effect on the transferability of these result to a national level.

[1] Further details of resources can be accessed at https://www.data.org.uk/for-education/secondary/stem-into-action-with-dt/.

Design of teacher questionnaire

The teacher questionnaire was designed to capture pre- and post- measures and was given to each participant teacher in each school at the beginning of the project before the intervention. Before the teaching intervention, the questionnaire requested participant teachers to give non-identifiable personal information and data about their teaching experience. The questions requested the individuals' gender, first degree, route for ITT, number of years teaching experience, the position of responsibility, amount of technical CPD and if their colleagues are supporting them on this project. The participant also provided a short description of the project they planned to teach, and the resources used.

The objective of this study was to assess D&T teachers' capability to deliver the technology curriculum. Considering teacher development to follow an effective or competency-based model (Menter 2010; Zeichner and Liston 1990), there is a range of knowledge and skills that D&T teachers can be expected to demonstrate in the classroom. Competence assessment is a useful way of assessing the performance of teachers as the competency model provides a measurable output (Voorhees 2001). This numeric output is a suitable method for use in quantitative educational research and has been used extensively (Gumbo et al. 2012). However, the difficulties in creating a competency model are the agreement of the definitions of competence (Huntly 2008).

This paper developed assessment metrics from competencies listed in the Design and Technology Association's D&T Progression Framework (Design and Technology Association National Curriculum Expert Group for D&T 2014). This framework utilises statements from the National Curriculum D&T programmes of study for Key Stage 3 (KS3), age 11–14, and additional points identified by the Design and Technology Association. The authors selected 25 statements to create a self-assessment tool related to technical knowledge statements from the following categories of the progression framework: Technical Knowledge, Making products work; Making, Practical skills and techniques; Designing, Generating developing modelling and communicating ideas. These statements were selected for this work to represent the overall technology competence of a D&T teacher, as they should be able to deliver all of these areas to their pupils.

However, Williams (2008) reported that respondents to questionnaires dislike being asked to rate their competence and prefer to be asked to rate their confidence. Williams used the self-report measurement of confidence as a proxy competence. Hargreaves et al. (1996) also found a relationship between self-reported competence and confidence in questionnaires for primary school teachers. Likert scales have been used to assess confidence in participants (Garbett 2003; Pritchard et al. 2002). In the study of nursing confidence and competence by Stewart et al. (2000), confidence, rather than competence, was considered to reveal if participants will perform a task.

Following the methods from prior research, participant teachers were requested to rate their agreement to 25 statements about their confidence in teaching the technical content of the National Curriculum. Their confidence was rated on a 7-point Likert scale (1 = No confidence, 2 = Unconfident, 3 = A little unconfident, 4 = Neutral, 5 = A little confident, 6 = Confident, 7 = Complete confidence). This section aimed to generate a score for teachers' confidence in teaching technical content before the start of the project and was used to compare to the score after the project.

After completing the new teaching with the resources, teachers were requested to complete the same assessment of 25 statements about their confidence in teaching the technical content of the National Curriculum. Finally, the questionnaire contained an open answer element, requesting participants to describe the best and worst aspects of the project they encountered. This was to gain positive and negative qualitative feedback on the project and to identify any other important outcomes that would not be discovered by the closed answer questions (Steele 1995). These qualitative data were used to understand further what challenges teachers encounter in delivering new STEM content and how that relates to their technology subject knowledge.

Quantitative and qualitative analysis

The quantitative results, taken from the pre and post measures of confidence in teaching assessment, have been calculated as non-parametric descriptive statistics of central tendency and variance. Box plots were used to represent the descriptive analysis of the competence statements. The descriptive statistics were used to categorise areas of strengths and weakness in technology teaching and identify if there are particular subject areas of concern. This analysis was used to answer how D&T teachers' subject knowledge prepared them for technology and engineering curriculum provision.

To assess the research question on technology curriculum provision, the change to teaching confidence scores as a result of developing and delivering new schemes of work were calculated. We expect that teachers with high levels of technology subject knowledge competence would be able to develop new schemes of technology-focused work. The results of the technology competence self-assessment, before and after teaching, were compared. As the data generated is non-parametric and contains two related-samples, Wilcoxon Signed Rank Tests methods were used to identify statistically significant changes in teachers' median scores in confidence of individual technology competence statements (Brace et al. 2012; Cohen et al. 2007). The data generated can be considered as a small sample as $N \leq 15$, where N is the number of pairs minus any tied ranks (Siegel and Castellan 1988). As the data from a small sample size, exact test statistics were calculated (Mehta and Patel 2013; Mundry and Fischer 1998; Sprent and Smeeton 2000). The effect size, *r*, is presented for each compared questionnaire item (Fritz et al. 2012; Pallant 2007). Where the effect is $0.1 =$ small effect, $0.3 =$ medium effect and $0.5 =$ large effect for each test of significance (Cohen 1988). Size effect was used to discuss the significance of the results concerning the small sample size. IBM SPSS Statistics 22 was used to perform this analysis.

The final section of the project questionnaire asked for teachers' positive and negative feedback to any aspects of the project. These qualitative responses were transcribed verbatim from the paper questionnaires, then thematically analysed (deductive analysis) and coded. Initially, the transcribed responses were read and re-read, and potential themes for analysis were coded. Key themes related to the research questions were extracted. The themes were refined through a second reading of the whole text and of the coded extracts already identified. The final themes and coded items are presented. Prevalence of themes is represented by uniquely coded extracts representing the number of individual teachers who were coded for each theme (Braun and Clarke 2006).

Table 1 Number of questionnaire responses and missing data

	Number of responses	Number of complete responses	Missing data (%)
Start of project teacher questionnaire	22	19	13.64
End of project teacher questionnaire	30	24	20.00
Both the start and end of project teacher questionnaires	18	15	54.55

Total unique teachers (N = 33)

Results

Participant and demographic data

From the 96 registered schools in the programme, 33 responses to the teacher questionnaires were received from 31 schools. The number of questionnaire responses and the amount of missing data from the responses is shown in Table 1.

The sample comprised 39% males (n = 13) and 48% females (n = 16), 12% not reported (n = 4). Most participants' first degrees were in a creative arts and design subject (n =16). The most common route for ITT was a 1 year PGCE course (n = 18). In descending order, the other routes followed for ITT were 2 year PGCE (n = 4), 3 year Undergraduate (n = 3), 2 year Teach First (n = 3), other (n = 1) and four participants with no response.

As can be seen in the results, there is a great diversity in the range of ways to study to become a D&T teacher in England. The amount of time spent in schools on teaching practices during ITT is always significant, governed by the legal requirements of Circular 9/92 and subsequently teaching standards (Department for Education 2013b). However, the amount of time spent outside of school learning subject knowledge and pedagogic theory differs. The undergraduate routes to teaching will also contain all the necessary subject knowledge (Williams 2009), while the 1-year postgraduate courses have very little time for subject knowledge development and work on the suitability of prior qualifications (Atkinson 2011; Banks 1997; Benson 2009). Although the time spent on aspects is different across courses, the content itself is similar (Owen-Jackson and Fasciato 2012).

The reported levels of teaching experience were high, with 20 participants having more than 5 years of teaching experience. The levels of experience were reflected in the seniority of the participants, with 16 participants in a position of responsibility within their subject or department. The amount of technology training undertaken by the sample was varied, with 8 participants undertaking no technology training. This was assessed by the number of half-days spent on technology CPD in a typical school year (n = 33, M = 2.39 95% CI [1.39,3.40], SD = 2.84).

As background qualifications are suggested to be a significant factor in the teaching confidence scores, the full detail of the participant's first degrees are in Table 2. The largest group, containing 62% of participants had BA degrees in creative arts and design subjects (n = 13, 90% CI [44.32%, 79.48%]). Due to the small number of results of non-BA creative arts and design subjects, there were no statistically significant differences in the data comparing between degree subject groups. However, this number is sufficient

Table 2 Background qualifications of participants

	Grouped first degrees			
	Architecture, building and planning	Business and administrative studies	Creative arts and design	Engineering and technology
BA	2	1	13	0
BSc	0	0	2	1
BEng	0	0	0	1
Other	0	0	1	0

Other degree types include CGLI, HNC, HND, BDes, MA, MDes, MEng

for an analysis of the results concerning background qualification. As the majority of the sample held a creative arts and design subject qualification, the authors consider this to be the background subject knowledge of the sample.

There is a similarity between the participants of this study and the estimated population data of D&T teachers by Jones et al. (2014). A z-test for two sample proportions calculated that there is no significant difference between the two proportions ($Z = .410$, $p > .05$, two-tailed). This comparison suggests that the sample used in this paper is similar to other studies, and therefore, the population of D&T teachers in England.

Initial teaching confidence scores

Central tendency and variance statistics were calculated to explore the responses to the individual teaching confidence items from the start of project questionnaire. The median, interquartile range (IQR) and range statistics are presented as box plots in Fig. 2. On the seven-point Likert scales used, values <4 represented negative confidence and >4 represented positive confidence. The box plot shows that the data is skewed towards high scoring responses. The competency statements have been categorised into teacher weaknesses, by their low or neutral median scores, or strengths by their high values for the entire IQR in Table 3.

Changes in teaching confidence scores following in-school intervention

To assess if there were any significant differences in confidence in technology teaching, between the start and end of the study, Wilcoxon Signed Ranks Test statistics were calculated to compare the start and end self-assessment scores for all teachers, for each competence item.

Combined results for all teachers showed a statistically significant increase in the median scores of teacher's confidence in technology teaching. There was a significant difference between time point 1 ($n = 19$, $Mdn = 5.4$, $IQR = 1$) and time point 2 ($n = 24$, $Mdn = 5.6$, $IQR = 1$) project scores for all teachers, found using a Wilcoxon Signed Ranks Test of Exact Significance (2-tailed) ($n = 15$, $Z = -3.150$, $p = .001$, $r = .58$).

The test statistics calculated, shown in Table 4, for the improvement in each competence statement, revealed that this overall improvement was a result of specific competency improvement, rather than an overall increase of all abilities. There were significant

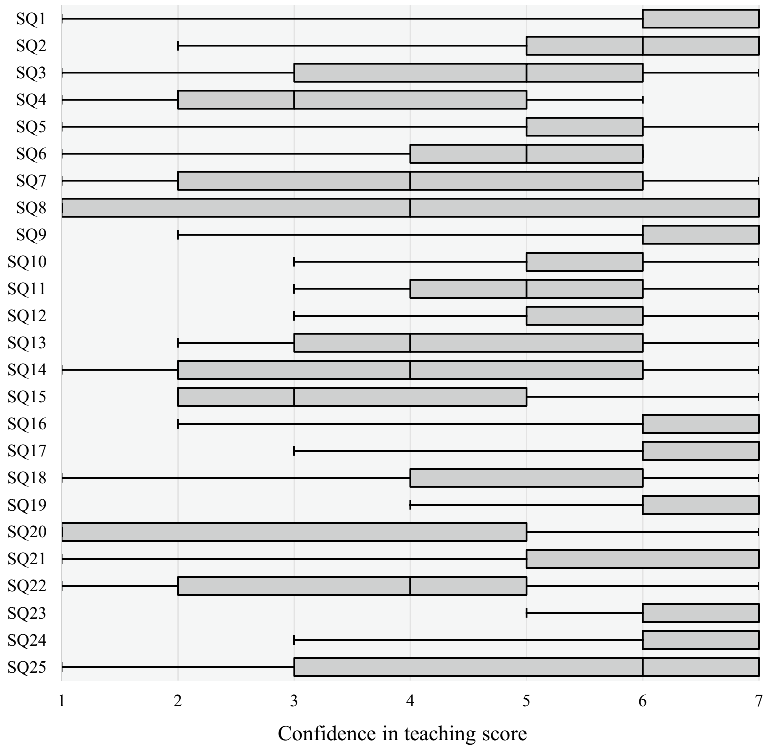

Fig. 2 Box plots of questionnaire item totals for teacher start of project questionnaire

Table 3 Strengths and weaknesses in teaching confidence

Strengths in teaching confidence	Weaknesses in teaching confidence
Q1. The classifications of materials by structure Q9. Using the correct technical vocabulary Q16. Measuring and marking materials and components accurately Q17. The use of CAM for scale of production Q19. Using hand tools and manual machines Q23. Health and safety Q24. Performing risk assessments	Q4. Designing products with compound gear trains or other similarly advanced mechanical systems Q7. Building 3D textiles from simple 2D fabric shapes Q8. Modifying the appearance of textiles using techniques such as dying or applique Q13. How to produce products that contain electronic sensors and outputs Q14. Programming Q15. Incorporating microcontrollers into their products Q22. Using CNC milling/turning/routing machines

improvements in teaching confidence scores for three items of the questionnaire. These were Q13, how to produce products that contain electronic sensors and outputs; Q14, programming and Q15, incorporating microcontrollers into their products. The remaining 22 items had no significant improvement.

Table 4 Changes in teacher scores between the start and end of the project for each item

Questionnaire item	Wilcoxon signed ranks test		
	Z	*p*	*r*
EQ1 > SQ1	0	1.000	.00
EQ2 > SQ2	− 2	.063	.37
EQ3 > SQ3	− 1.732	.125	.32
EQ4 > SQ4	− 1.414	.156	.26
EQ5 > SQ5	− 1	.500	.18
EQ6 > SQ6	− 0.707	.375	.13
EQ7 > SQ7	− 1	.313	.18
EQ8 > SQ8	− 0.447	.500	.08
EQ9 > SQ9	− 1	.500	.18
EQ10 > SQ10	− 1	.500	.18
EQ11 > SQ11	− 1.732	.125	.32
EQ12 > SQ12	0	.688	.00
EQ13 > SQ13	− 2.121	.031*	.39
EQ14 > SQ14	− 2.232	.016*	.41
EQ15 > SQ15	− 2.251	.016*	.41
EQ16 > SQ16	0	.750	.00
EQ17 > SQ17	− 1	.500	.18
EQ18 > SQ18	− 1.633	.125	.30
EQ19 > SQ19	0	.750	.00
EQ20 > SQ20	− 0.816	.375	.15
EQ21 > SQ21	− 1	.500	.18
EQ22 > SQ22	− 0.816	.375	.15
EQ23 > SQ23	0	1.000	.00
EQ24 > SQ24	− 1	.500	.18
EQ25 > SQ25	− 0.447	.500	.08

EQ End question, *SQ* Start question

*$p < .05$ level, Exact Sig one-tailed

Qualitative questionnaire responses

The coded responses were categorised into positive and negative feedback from the project. The thematically coded responses and the number of unique participants associated with the code are shown in Table 5. Key verbatim quotes from the teachers are provided in the analysis.

Benefits

Fourteen different participants reported that the project enabled teachers to develop new schemes of work. Participants stated that the resources enabled them to develop

Table 5 Thematic analysis and number of unique participant responses

Benefits	Obstacles
Developing new schemes of work (14)	Time constraints (10)
Developing pupils capability (11)	Difficulties with projects (6)
Pupil interest (7)	Cost prohibitive (5)
Discussing work with other teachers (7)	Teacher development (5)
Professional support (4)	Engaging pupils (2)
Awareness of subject (1)	Content of projects (2)
	Unsustainable in school (1)

new projects leading to a positive impact on the participants. Participant responses suggest that the resources enabled the development of new projects within the schools that expanded existing teaching methods. A STEM coordinator with more than 10 years teaching experience noted the benefits associated with doing something different "Chance to experiment and change the normal design/make agenda with the pupils." Further, a head of faculty with 6 to 10 years of teaching experience, described the perceived benefits of implementing a new scheme of work. "Being able to trial different resources with different groups and not being afraid to take risk."

Eleven participants reported that the project enhanced pupil learning and capability. A teacher with 6 to 10 years of teaching experience, described how pupil learning was improved: "[the resources were] relevant and useful for students. They can relate to it a lot more". A further participant with 6 to 10 years of experience, explained how they used the resources to provide links outside the classroom relevant to industry: "Linking outcomes to industry eg. Injection moulding.".

The participants also reported that the resources benefitted pupils by providing links to STEM subjects. This is important as the National Curriculum states that pupils should draw on their knowledge of maths and science and was recognised by participants. A subject leader with 1 to 5 years of teaching experience, described that the nature of the project allowed the application of maths and science in a D&T project: "The students were able to learn about relevant technology and understand a lot more applied science in practicality". A teacher with 1 to 5 years of experience, also reported including maths and science into the project: "Applying more maths and science knowledge to their practical projects. Linking D&T, maths and science into one project". These examples highlight that participants found the projects beneficial in providing an opportunity to deliver best practice D&T teaching, which incorporates science and maths in any given design. This is evidenced further by a head of faculty with 6 to 10 years of experience who described how the resources added learning opportunities which were not previously delivered: "Using new resources which challenged the type of content that we chose to deliver as a school—more experimental.".

Participants reported that pupils find electronics difficult, and this can lead to a lack of interest. Participants reported how the resources helped them to deliver the content to pupils in a more accessible way. Participants recognised that the resources provided a new starting point for teaching electronics, which was simple yet effective. A subject leader with 6 to 10 years of experience stated: "Simple way to introduce electronics as many students find this area difficult to grasp.".

Obstacles

The most frequently coded negative comment was about the time constraints placed on teachers and how such time constraints affected the delivery of the projects. A teacher with more than 10 years of teaching experience, provided an example of how time constraints impacted the delivery: “Lack of planning and preparation time prior to starting to use the resources”. Another participant, a teacher with 1 to 5 years of teaching experience added: “We were very time constrained in the project, therefore the quality of the finishing of the final project was not as good as it could be.”.

Six participants commented on having difficulties in implementing the projects. They identified problems that may occur when using a kit of parts to deliver a project such as a lack of depth in learning outcomes. A head of faculty with 6 to 10 years of teaching experience, commented on the limitations of some of the small projects: “Limited outcome eg. Picture frame”.

Two teachers commented on the difficulty to engage pupils with the technological resources available. A head of faculty with 1 to 5 years of teaching experience, commented on the problems they faced in engaging different age groups when delivering these projects. Year 9 marks the last year where technology teaching is compulsory in England, and it is, therefore, possible that teachers face difficulties because there are pupils with no interest in D&T: “[…] it’s difficult to engage those who have no interest in technology eg. In year 9”. If teachers were able to implement projects such as those in this study in earlier years, student engagement might improve.

Two participants commented that the content of the resources given was not suitable for their teaching because of a limited amount of information and that the resources did not fit the exam board specifications. A subject leader with 1 to 5 years of teaching experience stated: “Lack of classroom resource leading to evidence in books. I’ve attached some that I made, but we could have delivered more, faster, if the theory was more structured from the outset”. A subject leader with 6 to 10 years of teaching experience said: “Students still need to be able to use hand skills to satisfy exam board requirements.”.

Additional observations

The most popular resource was the LED balancing lamp project, ordered by more than 50% of participating schools. This resource had the potential to teach mechanics and utilise mathematics knowledge by requiring pupils to calculate moments to precisely balance the components in the lamp so that it could appear to hang off the edge of a desk. However, as exposed in teachers’ descriptions of lessons given, there was no evidence that any teacher included these activities in the balancing lamp project. Without the calculation and design of the balancing feature, the project becomes a low-technology level exercise of connecting an LED to a battery.

Discussion

The overall high scores in teaching confidence, reported by teachers, may be the consequence of self-reporting. Social desirability bias is participants giving what they think should be the right answer rather than their true feelings. This bias may explain that teachers consider that they should be confident (Podsakoff et al. 2003). This type of bias is expected with the chosen methods, and therefore, it is the relative ranking and comparative changes of the competency statements that are important to this discussion. Validation of findings is provided by the use of methodological triangulation (Guion et al. 2011), through qualitative and quantitative data generation. However, overestimation of ability is a trait of the unconsciously incompetent (Kruger and Dunning 1999; Robinson 1974). If the participants lack competence for the technical and scientific aspects of the technology in their classroom, they may be unable to evaluate their performance accurately.

As the project was intended to study and ultimately improve technology teaching in school, it is worth discussing the factors affecting D&T teachers' ability to develop resources and subsequent technology schemes of work. Three influences are proposed:

- The Department for Education consultation on teacher workload (Gibson et al. 2015) recognises that teachers are under pressure and that developing new schemes of work does take up teachers' time.
- The authors assume that teachers are motivated to teach their subject and to improve their technological teaching, as they have taken part in the "STEM into Action with D&T" project.
- Teacher's background subject knowledge expertise is in Creative Arts & Design, not Engineering and Technology.

Time pressures were the most commonly cited response of negative impact on the study, reported by 41% of participants on the feedback section of the teacher questionnaire. Reporting of time issues may occur because D&T teachers lack the time or support to learn sufficient technological knowledge as their starting point to deliver technology and engineering projects.

Teachers' positive comments report the successes of the 'Enhancing the teaching of STEM through Design and Technology' programme. Fourteen participants commented that the resources enabled the creation of new schemes of work, 11 participants reported that the project enhanced pupil learning and capability and seven reported the amount of interest pupils' had in the projects created. These comments demonstrate that teachers could develop schemes of work they considered successful from the resources available. However, the level of technology content that the participants included in their lessons was low and confined to basic programming and electronics assembly.

There was positive feedback made by an experienced teacher on the novelty of smart material resources. Competency 2, "how the properties of materials can be used for a design advantage (eg. grain, brittleness, flexibility, elasticity, malleability and thermal)?" which relates to smart materials had a high start of project confidence score, (Mdn = 6). While this appears to be a positive finding, these types of materials lessons should be familiar to schools as the topic of smart materials was explicitly named and introduced into the KS3 D&T curriculum over 10 years ago, yet they are novel to the participants of this study (Department for Education and Skills and Qualifications and Curriculum Authority 2004).

Participants commented that some resources were academically insufficient because they lacked the appropriate theory. These comments and evidence of weaknesses in teaching confidence suggests that teachers lack areas of subject knowledge theory in the individual STEM subject areas. Lack of subject knowledge is an important issue as studies have shown the link between subject knowledge and effective teaching (Banks 1996b; Hill 2008; McNamara 1991; Swackhamer et al. 2009).

The competency items classified as strengths are based on the making of products and using materials. The weaknesses are about the use of more advanced technology such as systems and control of mechanics and electronics and the use of specific 3D manufacturing technologies that require CAD knowledge. The weaknesses in teaching confidence suggest that teachers are least confident about teaching the areas of technology that required mathematics and scientific knowledge. The consequence is that low-level technology subject knowledge results in projects with low-level technology content (*op cit*).

Confidence in teaching scores collected before and after the projects were taught in school were analysed in this study. The analysis provided a comparison between the two scores to identify if teachers had used the projects to make improvements to their knowledge and teaching.

Overall participants reported that the project and resources had made improvements to their teaching confidence. There was a significant increase in the scores of teacher confidence in technology teaching ($n=15$, $Z=-3.150$, $p=.001$, $r=.58$). The individual items that had a statistically significant improvement in their scores were:

- Q13. how to produce products that contain electronic sensors and outputs ($n=15$, $Z=-2.121$, $p=.031$, $r=.39$).
- Q14. programming ($n=15$, $Z=-2.232$, $p=.016$, $r=.41$)
- Q15. incorporating microcontrollers into their products ($n=15$, $Z=-2.251$, $p=.016$, $r=.41$)

These results are statistically significant, and they demonstrate that the participants in the study may have been aware of their weaknesses in teaching electronics. They effectively used the resources to develop new electronics schemes of work to address these weaknesses. Feedback comments made by two participants that the resources had enabled teachers to simplify the learning of electronics for wider groups of pupils, adds verification to the statistical analysis.

The size effect calculated for these three statistically significant improvements to teaching confidence is medium. The small sample size may cause this weakness in the evidence of improvement or that only a small proportion of teachers felt they improved.

This finding has the potential to impact pupils' knowledge of technology significantly. However, the actual lessons developed from the resources contain very little technical content, as described above. Prior work on student outcomes from the project identified that student's motivation towards technology was not improved by these types of teaching interventions (Jones et al. 2018). Fourteen participants made comments that these resources were new and innovative in their classroom, which suggests that even this low level of technology provided by these resources is new to these schools. Compared to the KS3 D&T technical knowledge learning requirements from the National Curriculum:

> "understand and use the properties of materials and the performance of structural elements to achieve functioning solutions",
> "understand how more advanced mechanical systems used in their products enable changes in movement and force",
> "understand how more advanced electrical and electronic systems can be powered and used in their products [for example, circuits with heat, light, sound and movement as inputs and outputs]",
> "apply computing and use electronics to embed intelligence in products that respond to inputs [for example, sensors], and control outputs [for example, actuators], using

programmable components [for example, microcontrollers]" (Department for Education, 2013a).

Teachers appear to consider themselves able to deliver the technology curriculum. However, as discussed, there appear to be weaknesses in their capability to deliver the more advanced areas of the curriculum. The literature shows that teachers currently in school have developed a belief of how D&T should be taught from their prior experience of D&T as a pupil (Pajares 1992), from other teachers and mentors (Banks et al. 2004) and through exam boards (Atkinson 2000). It is possible that the beliefs held by teachers in what technology content should be taught are not suited to the needs of technology and engineering education.

These beliefs and the curriculum they create are resistant to change (Dow 2006; Drageset 2010; Lewis et al. 2005), which may explain the low improvement in teaching confidence scores observed. The subject knowledge background of the participants would at least contribute to the explanation of the technology teaching strengths and weaknesses observed. Without explicit technology subject knowledge, teachers would face expected difficulties in developing new high-technology level projects; and explain the cycle of teachers habitually running the same tired, low-technology level, projects (Atkinson 2000; Barlex and Rutland 2008; Zanker 2005).

There appears to be a subject-knowledge misalignment between the training and professional development requirements set by the government for D&T teachers and the subject knowledge that would best suit the interests of secondary school technology and engineering education. This misalignment would have the potential effect of not exposing young school pupils to the technology education desired for cognitive and affective development that could lead to engineering careers.

Limitations

A limitation of this work, for practical reasons, is the sole focus on technology teachers in England. Nevertheless, there may be commonalities between the English system and other systems that make this work of interest to an international audience. The teaching and curriculum requirements of middle school (9–13 age range) technology education is a diverse subject worldwide, complicated further by the lack of a clear established philosophy for technology as a subject (Ankiewicz 2015). There are many differences in initial teacher training routes internationally (Williams 2009), but they can be broadly categorised into two groups. For the most common route in England, teachers must have an undergraduate degree and then study for postgraduate qualifications in teaching. Postgraduate courses have very little time for subject knowledge development and work on the suitability of prior qualifications for subject knowledge (Atkinson 2011; Banks 1997; Benson 2009); Spain and France have similar systems. Countries such as Germany and Greece do not follow this separate content and pedagogy model, and technology teachers gain this combined knowledge at the undergraduate level, typically through a Bachelor in Education type qualification (Ginestié 2009; Williams 2009). Future research may specifically investigate the differences these teacher training systems have on technology educator's subject knowledge and make international comparisons.

This work does not evaluate the pedagogic methods used to deliver the projects or the effects of the "design" proportion of the tasks given to pupils. D&T is still a relatively new subject, and there is no universal solution as to how the subject should be taught (Banks 1996a, 1997, 2009; de Vries 2006), making the identification of 'correct' pedagogy unreliable. However, pedagogy and content are intrinsically linked as all knowledge delivered by a teacher is pedagogical in some way (Turner-Bisset 1999). Future studies should analyse the apparent size effects of the content and pedagogic method factors.

Another limitation of the work is the small sample size, with only 15 participants completing all elements of the questionnaire to enable full comparisons. This sample has potentially resulted in observing small and medium-size effects in the statistical analysis. While qualitative methods were used alongside the quantitative to provide validation for the statistical analysis of the small sample, future studies should target the specific subject knowledge effects. This subsequent study would require a large sample with enough teachers from a STEM subject knowledge background.

Conclusion

This paper has sought to assess technology and engineering teaching in D&T from the teacher's subject knowledge perspective to analyse to what extent prior subject knowledge has on technology and engineering curriculum provision. This analysis has continued development of an explanation for the difficulties faced in providing technology and engineering education to secondary school pupils.

The findings present a better understanding and awareness of teachers' technology knowledge and their confidence in teaching various aspects of the technology curriculum. A discovery made in the analysis of data was that teachers appear to be unaware of the level of technical detail required in teaching technology. As identified above, the levels of technology they are teaching are insufficiently fulfilling the requirements of D&T education, yet teachers report themselves to be confident and making progress in their technology teaching. Participants reported that the resources they were developing were making improvements to their lessons and contained new content. However, the content covered in the resources, such as electronics, smart materials and links to science and mathematics have been part of the National Curriculum for many years and should be already embedded into D&T.

The authors suggest that the lack of technology background results in reduced awareness of the broader aspects and purposes for technology and its links to engineering. The subject guidance does not explicitly state what technology should be taught (Design and Technology Association National Curriculum Expert Group for D&T 2014), and the choice of projects is given to teachers (Zanker 2008). Teachers are unaware of teaching deficiencies: an epistemology that results in the low level of technology content observed in this study. This research identifies the problems faced by the current body of teachers in trying to develop new technology project schemes of work based on free resources and project ideas. Their reported weaknesses in teaching were teaching modern mechanical and electrical systems, topics of high-technology and engineering subject level. Teachers lack time to learn everything they require to deliver new technology projects. The demographic data supports this conclusion. In this instance, the teachers lack sufficient technical background to develop technology projects or the time to learn a new field of speciality. Teachers require support in developing the subject knowledge in technology and in developing new pedagogical content knowledge to transform knowledge into classroom practice.

The key conclusion from this paper is that the previously suggested misalignment in the subject knowledge of D&T teachers and the knowledge required for modern technology and engineering education does affect technology curriculum delivery as presented in the findings of the study.

It is imperative to note that, rather than being a criticism of the quality of teaching provided, it is an observation that the subject knowledge standards for teacher training may be a significant factor. The consequence is that of inadequately providing the workforce to deliver the type of engineering education expected of higher education and industry.

The implications of this finding are significant to those engaged in engineering education as it has consequences on the expectations and assumptions that should be applied to secondary school technology and engineering education. The paper suggests that more significant impact may be achieved in secondary school outreach by allocating resources to focus on assisting and improving the capability of teachers, rather than merely providing free resources and expecting them to be delivered effectively. This paper has identified areas of weakness in teaching confidence, which could be the starting point for modular educational training programmes. The evidence presented suggests that professional development activities or changes to teacher training to empower technology subject knowledge development are required to improve secondary school technology and engineering education for pupils.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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