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Engineering science education: the impact of a paired peer approach on subject knowledge confidence and self-efficacy levels of student teachers

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ABSTRACT

Teacher performance has been linked with both self-efficacy and subject knowledge confidence suggesting that it is important to address these aspects within initial teacher training programmes. This study investigated the development of pre-service teacher's science and engineering subject knowledge confidence and teaching self-efficacy following participation in a paired-peer, multidisciplinary STEM project and assesses which aspects of the work may have resulted in any changes observed. A group of 10 pre-service teachers were paired with undergraduate engineering students to develop science through engineering challenges and to enact these with children. Multimethod pre and post evaluation assessed the impact of participation on the subject knowledge confidence and teaching self-efficacy levels of the pre-service teachers, alongside qualitatively exploring possible reasons for any changes. Results indicated that significant increases in both subject knowledge confidence and teaching self-efficacy had occurred. In exploring which aspects of the work may have contributed to these changes, data suggested that the paired-peer aspect of the project may have been beneficial. Immersing pre-service teachers in similar collaborative projects early in their career may provide opportunities to shape positive dispositions towards STEM subjects for pre-service teachers and so evaluations of how this can be built into teacher training programmes are required.

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STEM; engineering; science; teacher education; self-efficacy; STEM subject knowledge confidence

1. Introduction

A child's attitude towards STEM subjects (science, technology, engineering and maths) during their early education is known to influence their later interest in science and their choices about STEM based careers, with those who have a positive attitude being more likely to continue with their STEM studies into later schooling and beyond (Zubair & Nasir, 2011). This is particularly true for girls who develop their ideas

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about the appropriateness of STEM as a career at this early stage (Archer et al., 2012; EngineeringUK, 2015; Murphy & Whitelegg, 2006). It is therefore vital that we pay attention to how these attitudes can be positively influenced. The way in which STEM is taught in schools has been particularly identified as contributing to interest in and attitudes towards these subjects (Rocard et al., 2007). For example, an inquiry-led, active learning approach can motivate learners and help them to achieve many of the end goals of science education (Madhuria et al., 2012). Many advocate for an interdisciplinary approach where children experience STEM subjects in an inter-related manner (Banks & Barlex, 2014; Gomez & Albrecht, 2013). Such approaches not only provide opportunities to encompass real-world, problem-based learning into lessons (STEM Task force report, 2014) but also offer children realistic examples of how STEM subjects are encountered beyond the classroom. Engineering has the potential to provide a cohesive link across these disciplines (Bryan et al., 2015; Lucas et al., 2014; NGSS Lead States, 2013; The National Academies, 2014), leading to arguments for a greater inclusion of engineering and technology into school curricula, with a focus on design thinking and problem solving allied to this (Tytler et al., 2019). Accordingly, those countries which emphasise inquiry, problem solving, and creativity in their STEM curricula are those which perform highly in the PISA tables (Programme for International Student Assessment) (Marginson et al., 2013). Curricular approaches which aim to improve children's enjoyment of and attitudes towards STEM subjects through high quality integrated and inquiry-led teaching and experiences could therefore be vital if we are to have a suitably qualified future scientific and engineering workforce and to expand the talent pool (e.g. to include greater representation of women) from which future STEM expertise can be drawn.

Multidisciplinary approaches can therefore offer children cohesive, realistic experiences of STEM which can motivate them and help them to develop positive attitudes as well as potentially improving performance in STEM subjects. However, despite these advantages it remains in doubt whether or not STEM subjects, and in particular engineering, receive sufficient attention within the primary/ elementary curriculum of individual nations or states. For example; Australia, New Zealand and only four European countries highlight technology as a separate curriculum subject for this age group, with a further six merely incorporating this into the wider science curriculum (Marginson et al., 2013). There is also no single agreed model for a multidisciplinary STEM approach (Bybee, 2013) leaving the 'E' element of inter-related STEM approaches often underrepresented (Hoachlander, 2015). Encouragingly, some nations such as the United States and some Canadian territories are moving away from viewing STEM as a collection of different subjects towards a more multidisciplinary approach (Purzer et al., 2014; Tytler et al., 2019). However, even where there is specific curricular guidance about this, there are concerns over the adequacy and quantity of provision (Marginson et al., 2013). This results in an almost non-existent level of the integration of engineering into STEM activities at the elementary level internationally (Cunningham, 2009), suggesting that fully integrated approaches are rare.

It appears that many teachers at the primary/ elementary level remain confused about multidisciplinary STEM approaches, and how these can be embedded and sustained (Tytler et al., 2019) and that even where there is specific curriculum guidance related to such approaches there can be a lack of suitable professional development to support this (Purzer et al., 2014). There must therefore be other factors beyond simple curriculum coverage required to encourage and support teachers of younger children to fully and effectively adopt multidisciplinary approaches to teaching STEM. This paper aims to explore what these reasons may be and what teacher educators can do to potentially address this gap.

1.1. Literature review

Teachers who understand engineering design, what engineering is, what engineers do and the connections between science and engineering, are more willing and able to introduce and engage children in learning about engineers and engineering (Diefes-Dux, 2014) and incorporate this more integrally with science (Yaşar et al., 2006). This suggests that teacher science and engineering subject matter knowledge (SMK) is vital to the uptake and success of multidisciplinary approaches. Whilst it should not be assumed that all primary/ elementary teachers have insufficient understanding to integrate STEM subjects effectively, there have long been concerns over the STEM subject knowledge of teachers of children of primary age (particularly in the physical sciences) both in the UK where this study is based (Murphy & Whitelegg, 2006; Murphy et al., 2005; POST, 2003; Sharp & Grace, 2004; Sorsby & Watson, 1993; The Royal Society, 2010) and internationally (Akgün, 2009; Anggoro et al., 2017; Dawkins et al., 2003; Koc & Yager, 2016; Papadouris & Hadjigeorgiou, 2014; Potvin & Cyr, 2017; Stein et al., 2008). For example, in the US where, despite curriculum advice supporting STEM integration, elementary teachers have been repeatedly shown to have insufficient science content knowledge leading to a reluctance to adopt such approaches (Anggoro et al., 2017; Appleton, 2008; Appleton & Kindt, 2002). Concerns around teacher SMK could therefore potentially make the teaching of STEM subjects through a contextualised and inquiry based multidisciplinary approach problematic and may have contributed to the non-integration of engineering into STEM activities seen internationally (Cunningham, 2009).

Subject Knowledge is clearly an important factor in effective teaching, we cannot teach what we do not know, and teachers must have adequate SMK in order to help others learn it. However, SMK has been identified by Rowland et al. (2005) as only one of the elements of specialist teacher knowledge that needs to be in place for effective teaching to occur, meaning that SMK alone does not guarantee successful teaching (Almerico, 2011). A sole focus on SMK may therefore not be a sufficient indicator or predictor of one's ability to teach a subject effectively and indicates that other factors must be assessed if teachers are to become able to adopt fully integrated STEM approaches successfully.

It would seem that we must look towards the development of other factors, inclusive of but also reaching beyond content SMK in order to help primary/elementary teachers to become effective STEM educators. One such factor may be the confidence that these teachers have in their SMK (Chue & Lee, 2013). Without sufficient SMK confidence teachers can feel uncomfortable when teaching STEM subjects and adopt weaker, less integrated approaches (Bleicher & Lindgren, 2005; Harlen & Holroyd, 1997) which focus on information delivery rather than engaging the interest of pupils through active exposition or stimulating practical work (Ofsted, 2013), resulting in didactic, cautious teaching (Khwaja, 2006). However, teachers who have higher levels of confidence in their SMK have been associated with increased pupil achievement and motivation (Flores, 2015). Concerns around the confidence that teachers have in their STEM SMK appear to be long-standing. Half of the teachers in one survey conducted in 2007 identified SMK confidence as a major concern (Murphy et al., 2007) and this still appears to be apparent in classrooms today (Karatas et al., 2017; Kurup et al., 2019; Malandrakis, 2018). Teacher STEM SMK confidence therefore appears to potentially present a barrier to effective STEM education, possibly impeding the successful adoption of multidisciplinary STEM approaches and the integration of engineering education. With the foundations of STEM leaning and attitudes towards STEM subjects being laid down in the primary/ elementary years the need to address the SMK confidence (and therefore competence) of teachers is vital.

Whilst it would seem that SMK confidence is an important consideration for teacher development, again, it is not the sole concern. Teachers with similar levels of SMK and SMK confidence may still perform differently depending on their levels of self-efficacy (Bandura, 1993). The beliefs that individuals hold about their abilities and eventual outcomes are a powerful influence on how they will behave (Bandura, 1986). Self-efficacy is therefore a measure of a perceived ability, rather than actual performance, with teacher's self-efficacy being a belief in one's own ability to perform (namely, here, to teach STEM subjects) in a way that will have positive outcomes for learners (Gonzalez et al., 1990). Many studies have indicated a link between self-efficacy and teacher performance (Bates et al., 2011; Benz, 2012; Cantrell et al., 2003; McMullen et al., 2012; Palmer, 2006) where improved self-efficacy levels can result in teachers adopting more innovative teaching strategies (Flores, 2015). Consequently, teacher self-efficacy in science and engineering influences children's attitudes, achievement and motivations (McKinnon & Lamberts, 2014) with improvements in pupil outcomes, motivation and instructional behaviours observed where there were higher levels of teacher self-efficacy (Holzberger et al., 2013). However, it appears that even in countries with specific curricular guidance about integrated approaches often teachers do not have the levels of STEM teaching self-efficacy needed to support effective learning (Knaggs & Sondergeld, 2015; Rice & Roychoudhury, 2003), leading them to adopt more cautious, traditional and didactic teaching styles which may influence children's attitudes and achievements negatively (Burnett & Wichman, 1997). Again, this suggests that alongside a consideration of SMK confidence addressing the self-efficacy levels of teachers may be a further way in which the barriers to the effective integration of multidisciplinary STEM approaches could be removed.

Bandura's Social Cognitive Theory (SCT) (Bandura, 1977) proposes that learning occurs in a social context with a relationship and interaction of the person, environment and behaviour. It therefore considers the ways in which individuals acquire behaviour, and the reasons for that behaviour. This is extended to consider a variety of conditions under which self-efficacy may be associated (either positively or negatively) to psychosocial functioning and action and suggests that if people believe that an action will provide a favourable result and that they can successfully perform the action, then they will be motivated to perform that action (Bandura, 1977), thus demonstrating greater persistence to master challenging tasks (Bandura, 1982). However, this self-efficacy theory also suggests that one tends to avoid situations believed to exceed one's abilities or perceived capabilities (Bandura, 1977). Teachers who have low self-efficacy for STEM teaching may therefore simply avoid this element of the curriculum as much as possible, potentially further accounting for the lack of integrated and engineering approaches seen in the primary/ elementary phase. Furthermore, this avoidance denies them opportunities to experience success and positive outcomes and thus opportunities to enhance levels of self-efficacy. Self-efficacy therefore plays a critical role in closing the gap between thought and action. Unless teachers have positive experiences with multidisciplinary STEM approaches they may enter a cycle of avoidance and low self-efficacy. This then leads us to consider whether the provision of structured interventions designed to produce positive outcomes early on in a pre-service teacher's development could increase pre-service teacher's self-efficacy levels and help to create a positive cycle of self-efficacy development. This could potentially contribute towards changes in practice and possibly contribute towards removing one of the barriers to the successful integration of STEM approaches.

Bandura's Social Cognitive Theory (SCT) provides the theoretical framework for our proposal that self-efficacy can be developed through experiences with Bandura defining four factors which potentially contribute to this (Bandura, 1997):

- Mastery or performance accomplishments (i.e. experiences of relevant success);
- Vicarious experiences (i.e. comparisons of capability to others, modelling and observing);
- Verbal persuasions (positive feedback from peers and supervisors, coaching);
- Emotional arousal.

If self-efficacy beliefs can be transformed and can change in response to experiences, it is important to consider the nature of these experiences and how they relate to a teacher's development. Bandura (1997) suggests that self-efficacy may be most vulnerable to change during early learning and so a teacher's self-efficacy may be potentially most susceptible to influence and change during their initial training (Flores, 2015). However, with little literature available on methods to support pre-service primary/ elementary teachers in the development of STEM teaching self-efficacy (Menon & Sadler, 2018) this is presently difficult to address with any accuracy or certainty. It is therefore vital that knowledge concerning how these factors contribute to the development of teaching self-efficacy, could potentially be developed within the early experiences that pre-service teachers have, and therefore address this gap and contribute to the design of initial teacher education programmes.

With teacher performance and outcomes for pupils being linked to both teacher subject knowledge confidence and self-efficacy (Benz, 2012; Bleicher & Lindgren, 2005; Flores, 2015; McMullen et al., 2012) it is crucial to address both of these aspects with developing, pre-service teachers (Harlen & Holroyd, 1997), in order to possibly remove potential barriers in encouraging them to adopt a more rounded approach and to integrate these effectively in the classroom. The contribution that innovations designed to address these factors should therefore be evaluated and the lessons learnt or evidence gained used to inform the design of teacher education programmes. Our expectation is that teachers who experience opportunities mapped against the elements of Bandura's SCT theory could increase their levels of self-efficacy and SMK confidence, which could then in turn could potentially affect future classroom practice, aiding the removal of one of the barriers to the integration of STEM in the classroom.

This paper seeks to explore if participating in an engineering education initiative designed to address and incorporate elements of Bandura's self-efficacy theory will enable participants to experience an inquiry based multidisciplinary STEM approach to develop their SMK confidence and teaching self-efficacy for science and engineering. This paper therefore aims to evaluate the development of STEM SMK confidence and teaching self-efficacy of pre-service teachers, evaluating which aspects of a described intervention may have influenced any observed change and exploring ways in which it may have contributed to this change in order that recommendations can be made for teacher education programmes. The work described focusses on the use of a multidisciplinary STEM approach with an overarching engineering focus to teach science to UK primary school children. Pre-service teachers and undergraduate engineering students (from a variety of engineering disciplines) were paired together as peer-level partners to deliver pseudo-real-life, contextualised STEM based engineering challenges to over three hundred children in the south west of England. It is in this peer-pairing that this work provides novel opportunities and so this aspect therefore requires evaluation. This approach has been demonstrated to have a relevant impact on the engineering student participants in terms of their public engagement skills (Fogg Rogers et al., 2017). The potential impact that participation in this project may have had on the pre-service teachers is evaluated in this paper.

The research therefore aims to address the following questions:

(1) What impact (if any) does participation in a multidisciplinary paired peer approach have on the science and engineering SMK confidence and teaching self-efficacy for science and engineering for the pre-service teachers?
(2) Which aspects of the project may have contributed to any observed changes?
(3) In which ways does working with a paired peer potentially contribute to any observed changes?

2. Methodology

2.1. Sample and intervention

2.1.1. Sample

Participants in this study were 10 pre-service primary teachers enrolled in a three-year Initial Teacher Education (ITE) undergraduate degree at a university in the south of England. Participation in the study was voluntary following short information sessions given in lectures. All were in their second year of study apart from one in their third year and all were female. All pre-service teachers who volunteered were selected, meaning that the gender imbalance could not be controlled. All pre-service teachers who participated in the project had previously received training on scientific thinking and processes as part of their first-year studies and were also undertaking further science knowledge and pedagogy courses as part of their second (and third year) studies. All had at least 2 months previous experience in a primary school setting.

Half of the participants had opted to take a further module specialising in maths and science in their second year, with the others selecting a speciality in Art and Design, Languages or Steiner (Waldorf) education (studying the holistic educational philosophy and pedagogy of Rudolf Steiner see: https://www.steinerwaldorf.org/steiner-education/what-is-steiner-education/ for further information). Work undertaken as part of the chosen specialisms focussed on the role of a subject leader/ alternative education rather than enhanced subject knowledge content. These results can be seen in Table 1.

The 10 pre-service teachers were paired with 10 undergraduate engineering students from a variety of engineering backgrounds. These engineering students had also volunteered to be part of the project following an information and recruitment talk. They were in either their second or third year of three or four year programmes of study.

2.1.2. Pairing of the pre-service teachers and student engineers

When pairing the participants, levels of previous experiences of student voluntary schemes and previous experiences of working with children were considered. Undergraduate engineering students who had very little, or no previous experience of working with children were paired with those pre-service teachers who had the most experience in school settings. Where possible, the participants were also paired to give a mix of genders (not all of the engineering students were male so 8 of the pairings were mixed whilst in 2 of the pairings both participants were female). Finally, where these initial criteria had not resulted in a pairing, more subjective factors were taken into account such as ability to organise, communicate, to adapt and work flexibly where students with weaker skills were paired with a student with a corresponding stronger skill. Assessments of these were based on observations made by the tutors supervising the project during their previous experiences of working with each of the students.

2.1.3. The paired peer engineering intervention model

The two groups of students initially undertook training sessions separately and were then brought together within a knowledge exchange framework to explore a variety of engineering challenges and to plan how they could jointly deliver these and support children in school (Figure 1, and a more detailed outline in Appendix1). This work utilised the EU ENGINEER design challenges which are freely available on the project website (ENGINEERUK, 2015). These programmes use the Engineering Design Process (EDP) challenges for school children (aged 8–12), with the aim of raising awareness, knowledge, and attainment in STEM subjects and to engage children in engineering experiences which are multidisciplinary in nature and are contextualised in pseudo-real-life stories. Three key challenges were chosen on the basis of their suitability for the curriculum requirements of the schools hosting the project and to be the best match possible to the content of the engineering degrees being undertaken by the engineers. These challenges were; designing and building a floating platform for carrying items whilst swimming; creating a vacuum cleaner to remove classroom debris and building a glider to

Table 1. Participant characteristics.

Teacher Identity Code	Age	Gender	Chosen Speciality	Background
Teacher 1	19	Female	Steiner	White British
Teacher 2	20	Female	Art and Design	White British
Teacher 3	28	Female	Steiner	White British
Teacher 4	23	Female	Maths and Science	White British
Teacher 5	22	Female	Humanities	Asian British
Teacher 6	20	Female	Maths and Science	White British
Teacher 7	34	Female	Language and Literacies	Black British
Teacher 8	19	Female	Maths and Science	White British
Teacher 9	20	Female	Maths and Science	Asian British
Teacher 10	19	Female	Maths and Science	White British

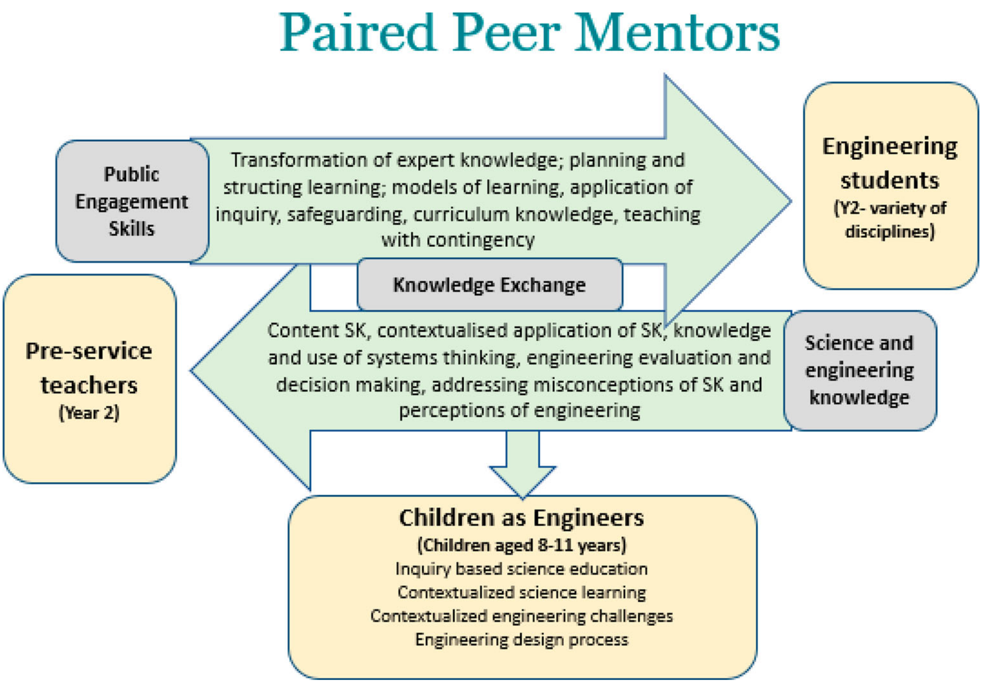

Figure 1. The paired peer model for knowledge exchange.

carry messages between friends. The challenges, their contextualised stories and the science SMK they cover are outlined in more detail in Appendix 2.

Each student engineer/ pre-service teacher pair spent 1.5 days in a local school taking classes of up to 30 children (aged between 8 and 11 years old) per pair, supporting the children through the engineering challenges. Schools that had not previously worked with the University on similar projects and who had reported that they were not well supported in terms of externally provided science or engineering interventions or activities were selected in order to minimise the influence of previous activities as far as possible. The school-based activities were supervised by school staff and the project team in order that support with organisation, behaviour management and help for children with additional needs could be provided if needed. Ethics approval was given by the relevant university committee and applied to the children, pre-service teachers and student engineers participating in the project. Consent for the children to participate in the intervention and any associated research was granted by the school and parents whilst the student engineers and pre-service teachers granted their own consent.

2.2. Research methodology

2.2.1. Student teacher subject knowledge confidence and science teaching self-efficacy levels

The evaluation of the pre-service teacher's STEM subject knowledge confidence and teaching self-efficacy was conducted as a pre and post longitudinal design over the length of the project (7 months). Data were grouped and anonymised for reporting.

The complexity of a teacher's knowledge and beliefs cannot be measured with a single technique and so levels of confidence in science and engineering were assessed using a multimethod design which focussed on the specific aspects of the pre-service teacher's confidence in their science and engineering subject knowledge and teaching self-efficacy. Both quantitative and qualitative research methods were employed, using questionnaires in combination with reflective diaries. This allowed the triangulation of data and so was more likely to capture 'the complex, multifaceted aspects of teaching and learning' (Kagan, 1990, p. 459).

2.2.2. Questionnaire design

The pre-service teachers completed paper questionnaires before and after their participation in the project. These consisted of the following aspects:

(1) Science Subject Knowledge Confidence scale (SSKCS) (defined as their personal confidence in their knowledge of science).
(2) Engineering Subject Knowledge Confidence' scale (ESKCS) (defined as their personal confidence in their knowledge of engineering).
(3) Teaching Science Self-Efficacy' scale (TSSS) (defined as the personal belief of the pre-service teachers in their abilities to positively affect children's educational attainments in science)
(4) Teaching Engineering Self-Efficacy' scale (TESS) (defined as the personal belief of the pre-service teachers in their abilities to positively affect children's educational attainments in science)

The four scales, prepared specifically for this study, were developed using the self-efficacy scale guidelines from Bandura (2006). Despite being novel scales the constructs were influenced by concepts outlined in the literature with the style, structure and purpose of the questions used based on those from the widely used and validated TESS scales (Yoon et al., 2012), the Maths Self-Efficacy scale (MSES, adapted for a science and engineering focus) (McMullen et al., 2012), the Science teaching outcome expectancy (version B for pre-service teachers) (Enoch & Riggs, 1990) and the STEBI-B tool (comprised of two subscales that measure Bandura's psychosocial construct) (Enoch & Riggs, 1990). Bleicher (2004) confirmed the integrity of the STEBI-B tool but found that the use of the phrase 'some students' instead of 'students' appeared to affect how respondents interpreted the statements (i.e. not all the students in a class). The TSSS and TESS scales used to analyse science teaching self-efficacy in this study were therefore adapted with this aspect amended. Initially, 15 questions were developed for each scale. The questions were reviewed by members of the project team, five wider academic staff at the university hosting the research and a group of 10 non-participating students (at the same stage and level of training as the participants). These reviews led to five questions being excluded from each scale to reduce the overall length and to avoid instances of repetition. Following reviewer's recommendations, the scope of the TSSS and the TESS were widened to include a greater focus on the skills required to work alongside children when undertaking engineering challenges (e.g. answering questions, guiding solution development and encouraging critical evaluation). The final 10-item scales were reviewed for readability by the authors.

To assess SMK confidence the pre-service teachers were asked to complete the SSKCS and the ESKCS. These scales consisted of ten Likert style questions asking for agreement about confidence in their science SMK and ten questions relating to their engineering SMK confidence e.g. 'I can recognise and appreciate the links between engineering and science concepts'. Items were scored from 1 to 10 based on how strongly the student agreed with the statement (with a score of 1 indicating low agreement and therefore low confidence and a score of 10 indicating strong agreement and high confidence). Numbers were chosen to represent the scale rather than words, as Bandura (2006) advises this range of options offers more discriminatory scalar analysis. In common with many self-efficacy scales, the score for both the science and engineering SMK confidence results were averaged across the whole 10-item scale in order to give a final mean value for each participant.

The TSSS and TESS scales were used to assess and evaluate teaching self-efficacy amongst the pre-service teachers. Researchers can assess self-efficacy beliefs by asking individuals to report on the strength of their confidence to accomplish or succeed in a task (Parajes, 1996). Accordingly, the TSSS featured ten questions asking for agreement about science teaching self-efficacy rated on a 10-point scale e.g. 'I will be able to explain and demonstrate scientific concepts in ways which will aid children's understanding'; and the TESS featured ten questions about engineering teaching self-efficacy rated on a 10-point scale e.g. 'I will be able to teach engineering as well as I teach other subjects'. Again, items were scored from 1 to 10 based on how confident the student felt (with a score of 1 indicating 'not confident at all' and 10 'totally confident'). A high score would therefore indicate strong confidence in one's ability to teach science or engineering effectively with strong expectations that children would learn successfully as a result of one's teaching. Science and engineering self-efficacy results for each pre-service teacher were determined by taking an average of the ratings for all ten questions to produce one mean value per scale. For each of these scales pre and post questionnaires were compared to indicate any potential changes in attitudes.

Open responses (qualitative) were also invited to gain further insight into the pre-service teacher's views about their SMK confidence and teaching self-efficacy. This section of the questionnaire asked 'How well equipped do you feel to teach science and engineering?' and 'Do you have any comments about your previous experiences of teaching science and/or engineering that you would like to add?'

2.2.3. Reflective diaries

The pre-service teachers were asked to complete three sets of reflective diaries following the two pre-service teacher focussed training sessions, the three joint knowledge exchange sessions and their experience in school to capture further qualitative responses to the project. These were completed electronically as due to time and geographical constraints it was not logistically possible to interview each of the pre-service teachers after each training session and school experience.

Open responses (qualitative) were invited to gain the participants own views about their progression, skills and confidence and to capture qualitative responses to the overall project. In this way, data gathered through the reflective diaries could be used to provide further evidence of levels of SMK confidence and self-efficacy and to also provide indications of aspects of the project that may have contributed to any observed changes. To guide responses given in these diaries, students were asked 5 broad questions. In order to more fully explore feelings of teaching self-efficacy these questions related to the four key characteristics which potentially contribute to self-efficacy identified by Bandura (1997) as defined below:

- Mastery or performance accomplishments e.g. What went well? What are you feeling confident about and what are you concerned about for the rest of the project?
- Vicarious experiences e.g. what was it like working with your paired peer?
- Verbal persuasions e.g. how did the children respond to you and your partner?
- Emotional arousal e.g. How do you feel that the session in school went?

Finally, the pre-service teachers were provided with an open space to add any additional thoughts that they wished to contribute.

2.2.4. Data analysis techniques

Quantitative questions were analysed using descriptive statistics in Microsoft Excel and then analysed using appropriate non-parametric statistical tests in SPSS v10. Qualitative responses were analysed separately by two of the project researchers using Thematic Analysis (Braun & Clarke, 2006) in QSR NVivo 10. Using a process of inter-coder constant comparison, the thematic hierarchies were combined.

3. Results

3.1. Subject knowledge confidence

The first aim of this research was to ascertain if participation in this project resulted in any change in science and engineering subject knowledge confidence.

Data derived from the pre-ESKCS indicated that all of the participants had initial low levels of confidence in their engineering subject knowledge (the average score for each pre-service teacher falling within a range of 2–4.4 out of a possible 10). This data was then used to generate a mean SMK confidence indicator for the group, indicating that the mean level of confidence in the pre-service teachers' engineering subject knowledge before the project was very low, at 3.3 ($SD = 1.8$). This was perhaps unsurprising as none of the pre-service teachers included in the project had been involved in any engineering education previously. However, data derived from the pre-SSKCS also indicated that confidence in science SMK before the project was also low (with all students falling between a range of 4.4 and 6.8 and a group mean of 5.5 out of 10 ($SD = 1.8$)) despite the fact that these pre-service teachers had all received previous science training as part of their ITE programme and had all taught science in primary schools previously (Table 2).

Initial qualitative data also indicated a lack of confidence in their science and engineering subject knowledge prior to the project. For all of the pre-service teachers, this focussed on their ability to answer questions from children whilst teaching in the classroom. For example, one participant (Teacher 7) stated that 'I am anxious about subject knowledge, how in depth could I answer questions.' Another (Teacher 10) reported that 'I need to gain more experience in teaching science so I know how to better answer questions.' In fact, it was this element of dealing with questions from children which appeared

Table 2. Pre and post participation group range and mean science and engineering SMK confidence ratings.

	Pre-Participation Test		Post-Participation Test	
	Group Range	Group Mean	Group Range	Group Mean
Mean science SMK confidence	4.4–6.8	5.5 (SD = 1.8)	6.7–8.6	7.5 (SD = 1.1)
Mean engineering SMK confidence	2.2–4	3.3 (SD = 1.8)	6.6–8.4	7.3 (SD = 0.9)

to be the barrier to pre-service teachers feeling confident about teaching science and engineering in general. For example, 'I am excited, but apprehensive about certain concepts arising that I may not be so confident answering' (Teacher 5) and 'I enjoy teaching science, however a lot of questions arise that need a lot more subject knowledge than I have' (Teacher 9).

Responses in both the post-ESKCS and the post-SSKCS indicated an increase in the science and engineering SMK confidence following participation in the project. All individuals had increased their engineering SMK confidence (with mean post-ESMKCS responses falling within a range of 6.6–8.4). The post- mean engineering SMK confidence value for the group was calculated at 7.3 ($SD = 0.9$), highlighting a highly significant increase ($Z = -2.81$, $p = 0.005$) from the pre-ESMKCS value of 3.3 (Figure 2, Table 2).

Despite having previous experiences of teaching science, there was also a change in the pre-service teacher's science SMK confidence with mean post-SSKCS responses falling within a range of 6.7 and 8.6, and a group mean of 7.5 (SD = 1.1) This change also appeared to be significantly higher ($Z = -2.82$, $p = 0.005$) than the pre- SSMKCS value of 5.5 (Figure 2, Table 2). Variations as to which of the pre-service teachers rated their confidence most highly were observed and did not appear to be related to which speciality they studied. Although visually the standard error bars are shown to overlap in Figure 2, the statistical tests used to determine a difference between the pre and post results, at the degrees of freedom and levels of significance conclusively show a difference in the pre-service teacher's confidence in both the science and engineering subject knowledge.

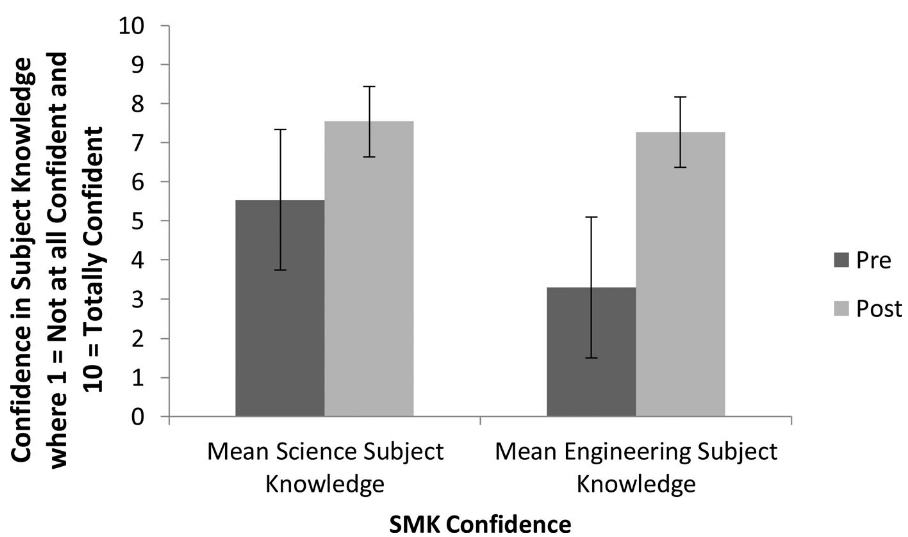

Figure 2. Student teachers' confidence in science and engineering subject knowledge.

3.2. Teaching self-Efficacy

As well as determining changes in subject knowledge confidence, an initial aim of this research was also to ascertain if participation in the project contributed to changes in the levels of science and engineering teaching self-efficacy for the pre-service teachers. Responses from the TSSS and the TESS indicated increases in science and engineering teaching self-efficacy had occurred.

Pre-TESS data indicated that mean self-efficacy levels for the pre-service teacher's confidence in their ability to teach engineering before participation in the project was low, with responses falling within a range of 3–4.8. A group mean was calculated at 4.1 out of 10 ($SD = 0.9$). Following the project, the mean TESS self-efficacy ratings fell within a range of 7.5–8.2 with all participants indicating an increase in their self-efficacy levels. The group mean TESS value of 7.8 ($SD = 0.4$) indicated a highly significant increase ($Z = -2.81$, $p = 0.005$) in self-efficacy levels of pre-service teachers to teach engineering following the project (Figure 3, Table 3).

Before participation in the project each of the pre-service teachers indicated a moderate level of self-efficacy for the teaching of science (with mean pre-TSSS responses falling within a range of 5.4 and 7, and a group mean of 6.3 out of 10 ($SD = 0.9$)). Following the project, the mean TSSS responses fell between a range of 7.3 and 9.2 with a group mean value of 8.2 ($SD = 1.0$). There was therefore, again, a significant increase ($Z = -2.81$, $p = 0.005$) in the self-efficacy levels of the pre-service teachers towards the teaching of science following participation in the project (Figure 3, Table 3). As previously observed, there were variances in the highest scoring students which did not appear to relate to their subject speciality. However, those rating themselves most highly for their subject knowledge confidence were also those rating themselves most strongly for their teaching self-efficacy, indicating a potential link. An increase in the self-efficacy levels for the teaching of engineering may be expected due to a lack of previous experience. However, the

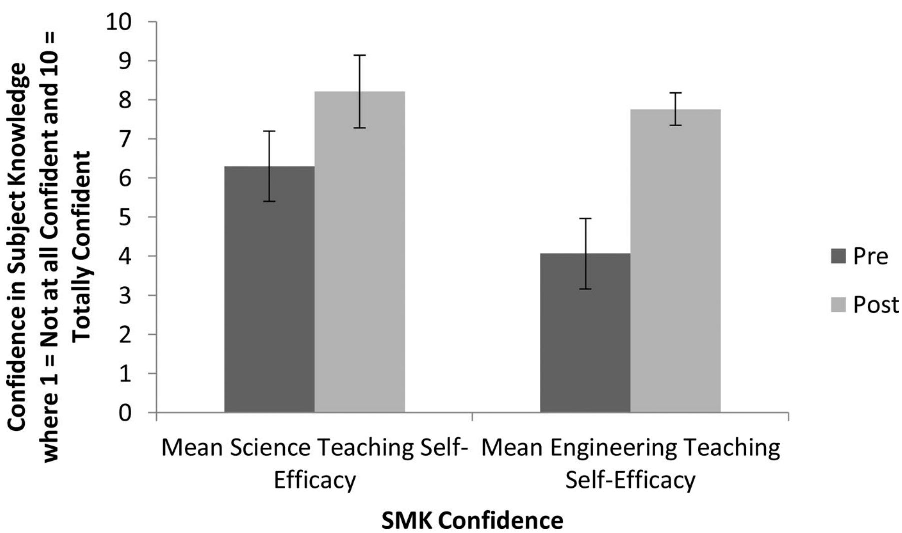

Figure 3. Student teachers' self-efficacy levels for teaching science and engineering.

Table 3. Pre and post participation group range and mean science and engineering self-efficacy ratings.

	Pre-Participation Test		Post-Participation Test	
	Group Range	Group Mean	Group Range	Group Mean
Mean science self-efficacy rating	5.4–7	6.3 (SD = 0.9)	7.3–9.2	8.2 (SD = 1)
Mean engineering self-efficacy rating	3–4.8	4.1 (SD = 0.9)	7.5–8.2	7.8 (SD = 0.4)

confidence that the pre-service teachers had in their ability to teach science also significantly increased regardless of their previous experiences.

3.3. Thematic analysis

Thematic analysis of the content of the reflective diaries and qualitative comments included in the post-questionnaires revealed a number of thematic hierarchies (Table 4). The number of times each theme was referenced suggests its relative importance. Amongst the strongly emerging themes was that of 'personal learning' where, like the quantitative data, the comments again indicated an increase in SMK confidence. All of the pre-service teachers stated that they had increased levels of confidence in their science and engineering SMK following participation in the project. For example, one participant Teacher 7 stated 'My engineer partner explained terms and concepts in a way that I would understand. For example, with words such as, force, gravity, thrust etc. I feel much happier about using these now'. The qualitative data also indicated that the pre-service teachers felt better equipped to teach science and engineering in the classroom, mirroring the increased self-efficacy observed in the quantitative data. Teacher 3 stated; 'I have a much better understanding of the engineering materials that I have presented so I felt comfortable doing this' and Teacher 10 'I feel like I will be able to help my pupils make progress with their engineering knowledge and skills now'.

The quantitative data indicated that those rating themselves most highly for their subject knowledge confidence were also those rating themselves most strongly for their teaching self-efficacy (but this did not again appear to be related to the previous subject specialism chosen by the pre-service teacher). Interestingly, the qualitative data also indicated a potential link between these elements. Teacher 6 said, 'I feel much more confident with knowledge and in having a successful engineering lesson' and Teacher 3 reported

> Meeting up before the first teaching lesson was great … we went through the science in so much detail. When we came to teach it it's the best I have ever felt in a science lesson! It was good to really understand what I was teaching,

indicating that confidence in their SMK resulted increased confidence when teaching. Some participants related this to their ability to transform their own understanding into a form suitable for the children e.g. 'I will be able to explain the science behind why everyday products work' (Teacher 1), and 'Now I think I can explain and demonstrate scientific concepts in different ways to aid children's understanding' (Teacher 7) and again, many linked this to their ability to answer questions and provide explanations. One participant (Teacher 9) asserted, 'I think that by following the EDP (Engineering design Process) I will be confident enough to answer questions.' With Teacher 4

Table 4. Coded themes and frequency of responses within these themes from the pre-service teachers.

Theme	Codes	Typical responses	Number of References
Children's Responses	**Enjoyment** children's engagement, enthusiasm and enjoyment	'Many of them asked really good questions and made lots of good points' 'They loved the idea that they were engineers'	7
	Gender differences in the perceived interest and engagement of boys and girls	'Many of the girls were fully engaged and some took control over the boys, they said that although they had previously thought only boys could do it'	2
	Inspiring Children children stating a future interest in STEM/engineering	'One boy said to me "I love Science now because it is very fun and not that difficult" another said "it was epic, I really liked being an engineer. I gonna be a engineer"' 'After today though I think in their future when it comes to making some decisions about their potential careers they will not just dismiss engineering straight away'	3
	Learning perceived improvements in children's understanding of the science topics covered and understanding of the nature of engineering	'I believe the children learnt a lot as by the end of the day they had a clear understanding of what they were doing and why. They were able to describe why something was reacting in a particular way to something else which at the beginning of the day they couldn't' 'The children learnt quite a bit about what engineering is. This was evidenced when we asked them to write what they thought it was on post-its at the start of the day and then again at the end'	7
	Responses to the Students Children's reactions to the students and engagement with them	'The children responded very positively to me and my partner' 'Some children commented on us being nice, fun and friendly'	6
Materials	**Resources** provision of, usefulness and appropriateness of the engineering materials	'Some of the equipment was not sturdy enough and not stored properly which meant that time was lost doing repairs' 'Some of the equipment we were using was breaking and this was a source of frustration for the children'	5
	Engineer Teaching Materials structure, usefulness and appropriateness of the teaching materials	'My only negative was the amount of worksheets, they became quite laborious and therefore we Skipped quite a few. I found them slightly repetitive' 'The length of activities weren't balanced well, for example I had to cut out a section and change the length of others'	6
Personal Reflections/ future practice	**Personal Enjoyment** student's own enjoyment of participating	'I've really enjoyed it so far, it's great experience'	6

(*Continued*)

Table 4. Continued.

Theme	Codes	Typical responses	Number of References
	Future Practice of Teaching thoughts to be carried forward to impact on future practice	'I'm quite likely to repeat parts of the lessons' 'I will think about how to make sessions more practical and engaging like this through using the engineering process'	20
	Personal Learning improvements in own understanding of and confidence in engineering and science SMK, ability to answer questions posed by the children.	'More confident in teaching the knowledge about circuits in science' 'it has helped me understand the terms and concepts better and to be explain them in a way that the children would understand'	14
Working with a Peer	**Shared Workload** distribution of work, being able to address all work needing to be done by having a partner	'It helped the children during the activities as there were enough adults assisting them in their work' 'It was great as it meant that we were able to share up the work like one person creates the PowerPoint, one makes the launches and the other makes and models the gliders'	4
	Sharing Expertise recognition and deployment of recognised differences in strengths and expertise	'we really complimented each other's strengths. I would tell them what we were going to do, organise the lesson and ask questions (intending to further their learning) and my partner would give really great explanations and clear examples of what we were teaching and take over the reigns as soon as I implied that I needed him to 'my partner and I bounced off each other well and each had our own areas of specialism in order to help the children in different areas'	10

adding 'I feel like I will be able to ask good questions about science and engineering to help my pupils to learn' and Teacher 6 feeling that they would be to 'answer pupil's questions (relatively) easily'. Here, the pre-service teachers appear to be indicating that without feeling confident that they had a secure SMK basis they would feel less confident in their ability to teach.

3.4. Analysis of the impact of the project model

Figure 4 shows the number of codes emerging (and therefore their relative strengths and assumed importance) in each of the themes in the reflective diaries. The most strongly emerging theme was that relating to the pre-service teacher's thoughts about their future practice. All of the participants indicated that they would like to, and intended to adopt either an inquiry-based approach to teaching science and/or a multidisciplinary, science through engineering approach when practicing as fully qualified teachers. Whilst it is interesting to note this alongside the observed changes in SMK confidence and self-efficacy, if lessons for future teacher development programmes are to be learnt, it is also important to consider the final research aim of the project which attempts to assess which aspects of the project may have contributed to any observed changes and the potential impact of working with a paired peer in any observed changes.

In determining which aspects of the project may have contributed to the observed changes the codes grouped under the theme of children's responses appear to have been important to the pre-service teachers, enabling them to see the impact of their work on the children's enjoyment, learning and future aspirations towards STEM. However, the theme related to the opportunity to work alongside a paired peer also emerged strongly. The quantitative data also reflected this, showing that working in a partnership with a paired peer was one of the most rewarding aspects of the project ($M = 4.86$, $SD = 0.36$) (Figure 5). Whilst the sharing of workload was mentioned by some participants it was the sharing of expertise which emerged more strongly in the analysis.

The qualitative open questions and reflective diaries provided insights into why this was so; namely that the peer pairing meant that the partners had complementary skills and knowledge and the opportunity to share and develop these. Illustrating this, Teacher 4 stated that: 'I think the combination of pairing engineers and teachers for this activity works well.' Other quotes related to the development of SMK, SMK confidence and teaching self-efficacy resulting from the paired work. For example, 'I am more confident about teaching about forces now as my partner explained it to me really well when we worked on the model together' (Teacher 5). This paired sharing of

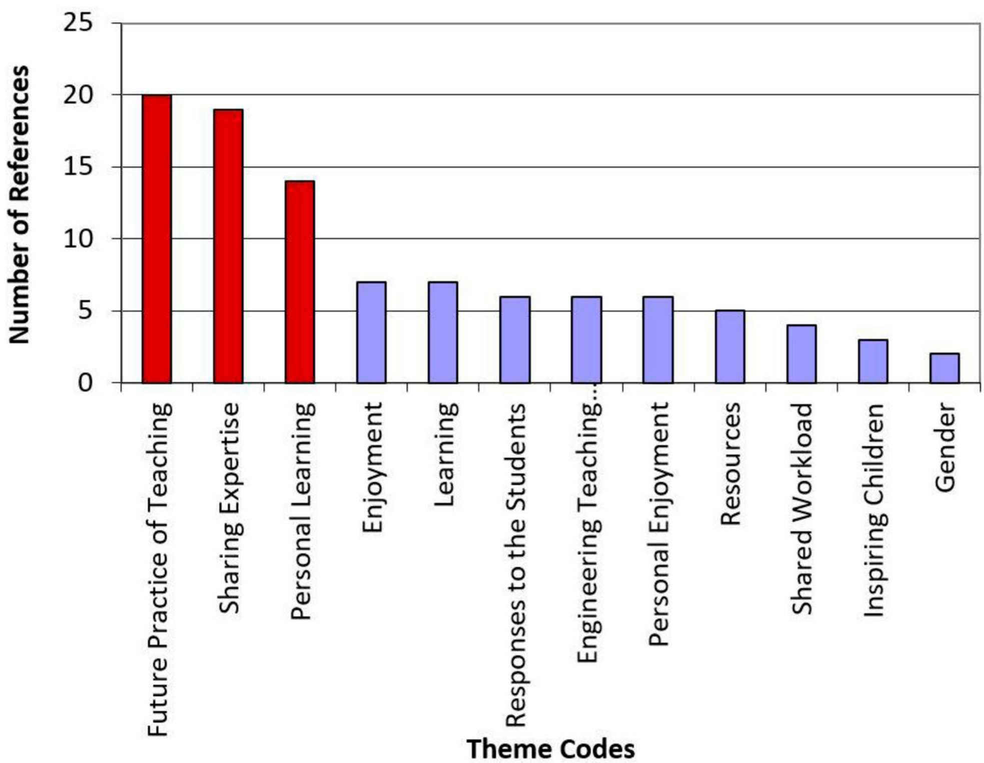

Figure 4. Number of codes related to each of the themes arising from the reflective diaries.

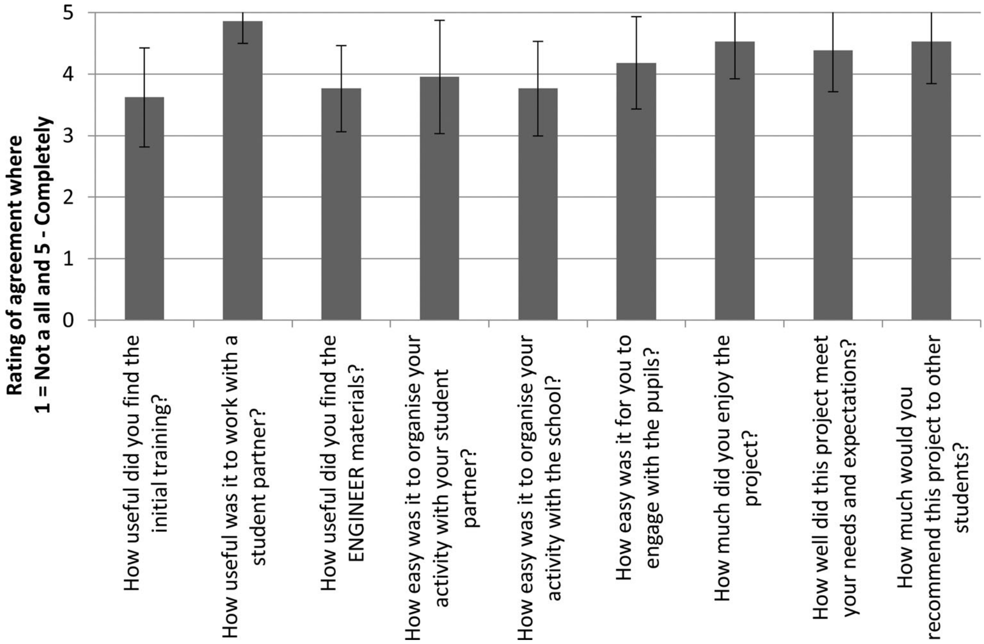

Figure 5. Feedback ratings from student engineers and teachers on the Paired Peer Mentors Project.

expertise appears to have been important both during the initial paired sessions (e.g. Teacher 4 'I felt comfortable saying when I didn't understand something to my engineer. Together, we worked out a way to explain things in simple terms' and Teacher 10, 'Having the subject knowledge nailed down by my partner really helped me to structure the lessons for school') and in the school-based activities (Teacher 1 'My partner really understood the gaps in the children's knowledge and stepped in brilliantly. I learnt so much from him'; Teacher 2, 'My partner was very helpful. There were instances where my engineering knowledge was not quite there and I could turn to him for help … … I could do this again really well now' and Teacher 5 'Sometimes I would have to "translate" the explanation given by my engineer into terms that the children could understand more easily. This really pushed my own understanding so I surprised myself at how well I did').

The high emergence of codes within the 'Personal Learning' and 'Sharing expertise' themes and the SMK confidence and teaching self-efficacy focus of these codes not only strengthens the assertion that participation in the project results in improved levels of SMK confidence and teaching self-efficacy but also suggests that improvements seen in these areas may have been influenced by the paired-peers aspect of the model.

4. Discussion

Even where there is specific curricular guidance about adopting multidisciplinary approaches to the teaching of STEM, many teachers remain confused about how such approaches can be embedded and sustained (Tytler et al., 2019) leading to concerns over the adequacy and quantity of provision (Marginson et al., 2013). The confidence that teachers have in their STEM SMK and their levels of STEM teaching self-efficacy appear to present a barrier to effective STEM education (Chue & Lee, 2013; Knaggs & Sondergeld, 2015; Rice & Roychoudhury, 2003), potentially impeding the successful adoption of multidisciplinary STEM approaches and the integration of engineering education. This paper aimed to explore how pre-service teachers can be supported in this aspect of their development and what teacher educators can do to potentially address this gap.

In addressing the initial research aim, data collected throughout the research indicated that participation in the project resulted in increases in the science and engineering SMK confidence and teaching self-efficacy levels for the pre-service teachers. Significant increases were initially evidenced in the quantitative data, and also indicated in the qualitative data where reflections under the themes of 'personal learning' and 'sharing expertise' related to increased SMK confidence and self-efficacy, associating this to classroom practices such as a perceived improved ability to deal with the SMK challenges around questioning (mirroring findings by Flores (2015) and Harlen and Holroyd (1997)). This was again echoed in the 'critique of the materials' theme where all the pre-service teachers in this project reported that they adapted and personalised the engineering teaching materials. Pre-service teachers tend to rely heavily on curriculum materials particularly for inquiry-based science activities (Avraamidou & Zembal-Saul, 2010). However, Forbes (2013) suggests that critiques and adaptations arise as a result of teacher's knowledge, beliefs, identities, and orientations, suggesting that the willingness to personalise teaching materials could potentially further indicate improved levels of SMK confidence and self-efficacy. The most strongly emerging theme from the thematic analysis was that of 'future practice' and the reported intention to adopt inquiry based multidiscipline approaches in at a later date in the classroom. Whilst it would be incorrect to define a causal link between the increased SMK confidence, self-efficacy and intentions for future practice it could be assumed that the pre-service teachers have not entered the negative cycle of lowered teaching self-efficacy and an avoidance of or reluctance to teach STEM subjects in a multidisciplinary approach as observed by Anggoro et al. (2017); Appleton (2008); Appleton and Kindt (2002) and Koc and Yager (2016), strengthening the assumption of positive impacts on self-efficacy.

Whilst it is difficult to ascertain whether increased self-efficacy arose from improved SMK confidence or vice versa, much of the analysis suggests that they may be developed in tandem. The potential link between these factors indicated in these findings merit further investigation in future research. However, as such increased levels of teacher SMK confidence and self-efficacy are known to be associated with improved pedagogical practices (Benz, 2012; Bleicher & Lindgren, 2005; Burnett & Wichman, 1997; Flores, 2015; Harlen & Holroyd, 1997; Holzberger et al., 2013; McMullen et al., 2012; Ofsted, 2013), and with international concerns around these factors for teachers and pre-service teachers (Karatas et al., 2017; Kurup et al., 2019; Malandrakis, 2018; Murphy et al., 2007; Shahali et al., 2015) these changes are interesting to note. This is especially interesting amongst an all-female group of pre-service teachers as female teachers in particular can struggle to have the levels of self-efficacy required to support effective classroom practices and therefore learning (Bleicher, 2004).

The increased levels of SMK confidence and self-efficacy coupled with the reflections from all participants about their intentions to adopt such an approach in future practice therefore indicate that the project model could have the potential to remove some of the barriers to encouraging teachers to adopt inquiry based multidiscipline approaches with consequent advantages for classroom practice.

Caution should be noted when considering SCT and when assessing the outcomes of all self-reported data. In this study, a reported increase in SMK confidence and self-efficacy should not be assumed to be linked to increased SMK itself. However, it is unlikely that a pre-service teacher finding themselves in a classroom with insufficient SMK would report an increase in SMK confidence and self-efficacy. The observed changes may have also simply been due to the immediacy of having undertaken the project and that subsequent, more negative experience may damage or reverse any long-term effect. It is therefore recommended that a more longitudinal view is taken to assess longer term impact as it is the maintenance of behaviour which is important, rather than initiation of behaviour alone. Despite these concerns the results do suggest that STEM SMK confidence and self-efficacy are not fixed and can be developed in response to certain experiences and so the mechanisms leading to such changes require further investigation.

With little literature available on methods to support pre-service teachers in the development of STEM teaching self-efficacy (Menon & Sadler, 2018) the second aim of this research was to assess which aspects of the project may have contributed to any observed changes in order that suggestions could be made to address this gap. The very nature of the tasks undertaken by the students in this project have been identified as tasks that typically contribute to the building of self-efficacy, including; classroom teaching opportunities (Bandura, 1982, 1997; Bautista, 2011) and engaging in inquiry-based science investigations (Gunning & Mensah, 2011; Mulholland & Wallace, 2001; Soprano & Yang, 2013). Sometimes, simply having the opportunity to teach a science lesson or to have in-class discussions can positively impact self-efficacy (Bautista 2011; Gunning & Mensah, 2011). However, this is not always the case (Gencer & Çakirolu, 2007; Wagler, 2011), and in fact, the pre-service teachers who participated in this project had experienced many of the aspects described above in their previous science education training but still appeared to have initial low self-efficacy levels. Self-efficacy beliefs are most likely to change when individuals are faced with novel tasks (Usher & Parajes, 2008). Therefore, exploring what is novel about this approach, and therefore may have contributed to these new observed changes in SMK confidence and self-efficacy requires analysis.

Bandura (1986) states that mastery or performance accomplishments contribute to developing self-efficacy and accordingly a correlation between positive field experiences and increased levels of self-efficacy for early or pre-service teachers is often observed (Li & Zang, 2000). Having an opportunity to experience perceived success of a novel experience such as the science through engineering approach (as indicated by the strongly emerging positive ‘childrens’ responses’ theme from the pre-service teacher’s reflections) may have therefore been a factor in the observed changes. Likewise, the novel requirement of having to complete ongoing reflections on their own development may have enabled the pre-service teachers to notice a gradual improvement in their skills throughout the project. Undergoing a mastery experience such as this can be one of the most influential factors in determining self-efficacy beliefs because the reflections provide evidence as to whether students can master tasks (Brand & Wilkins, 2007; Usher & Parajes, 2008).

Social models play an important role in the development of self-efficacy (Usher & Parajes, 2008), especially for individuals such as the participants in this study who are uncertain about their own abilities and are in their early stages of development (Bandura, 1997; Flores, 2015) and so their role in the development of self-efficacy should be assessed. The true novelty of this approach is in the peer pairing element and so an exploration of the potential impact of this formed the final research question. The paired peer mentoring model was positively reviewed by the pre-service teachers (Figure 5) with the aspect of working with an expert peer being a strongly emerging outcome of the thematic analysis (Table 4). Many of these comments pertained to the sharing of workload indicating that any pairing would be beneficial but the sharing of expertise also emerged as a reoccurring theme. The peer to peer work used within this study discouraged the pre-service teachers from working in isolation and instead encouraged discussion about both subject knowledge and understanding as well as pedagogy. Correspondingly, many of the pre-service teacher's reflections were associated with thoughts around SMK confidence development indicating that this occurred during the shared experiences both before and during the school-based activity. When students collaboratively design and build artefacts that require relevant understanding and application of science, many aspects of scientific literacy are developed (Chue & Lee, 2013). Similarly, in this study, the engineering students shared their expertise of the scientific basis of the challenges with the pre-service teachers as they themselves worked through the engineering challenge before their school-based experience. Cordingley et al. (2005) argued that collaborating with peers to share knowledge and expertise in such a manner enhances teacher confidence, alongside improving classroom practice and helps teachers to become more prepared to teach science, with Britton (2010) stating that this also improves their attitude toward it. It appears that collaborating with an 'expert' peer whilst working through and planning the engineering challenges opened up dialogue and a sharing of subject knowledge expertise which potentially contributed to the increased levels of SMK confidence and self-efficacy observed. Whilst we often pair pre-service teachers with more experienced teachers these findings suggest that we should also recognise the potential benefits of pairing pre-service teachers with their peers. Many of the participants reported feeling comfortable with working with their paired peer. Having a partner who is a 'peer' may be a significant factor specifically in building confidence as vicarious information gained from those perceived as having similar attributes (e.g. age) are often powerful sources of self-efficacy information (Usher & Parajes, 2008). The power of the paired peers may emerge from the social persuasion that comes with negotiating differences of opinion (Mintzes & Marcum, 2013) with such engagements encouraging students to think of themselves as subject specialists and discuss their experiences as professional peers (Woolhouse & Cochrane, 2009) whereas this may be more difficult with figures viewed to be in more authoritative positions.

With teacher performance and outcomes for pupils being linked to both teacher subject knowledge confidence and self-efficacy (Benz, 2012; Bleicher & Lindgren, 2005; Flores, 2015; McMullen et al., 2012), it is vital to address these aspects in order to help teachers to adopt more innovative teaching strategies (Flores, 2015). It would seem pertinent that interventions are put into place early in training and development and that aspects of training and experience which are determined to be effective contributors to change in subject knowledge confidence and self-efficacy become part of teacher development programmes. The opportunity to collaborate in the design, implementation, and evaluation of a STEM problem-based project seems to be a powerful experience for many participants, with the collaborative, peer element appearing to have been a significant factor in helping to improve both the subject knowledge confidence and self-efficacy of the pre-service teachers.

5. Conclusion

Teachers who have positive attitudes and are enthusiastic about teaching a subject, seek out growth opportunities, stay current and create connections with the subject matter that are meaningful to their students (Singh & Stoloff, 2008). Those who lack confidence adopt weaker pedagogical approaches (Bleicher & Lindgren, 2005; Harlen & Holroyd, 1997) leading to poorer outcomes for pupils (Ofsted, 2013). Teacher subject knowledge confidence and self-efficacy should therefore be positively addressed early on in the training of potential teachers if we wish to enhance outcomes for pupils. At present, teacher education programmes appear to have little impact upon the way in which new and student teachers view themselves as teachers (Ballantyne et al., 2012). However, with evidence suggesting that a pre-service teacher's self-efficacy has the potential to be significantly influenced by their training (Flores, 2015), initial teacher education programmes present a critical opportunity to influence and develop pre-service teacher's subject knowledge confidence and self-efficacy and potentially, their future practice.

An analysis of factors within initial teacher education programmes which can lead to meaningful changes in subject knowledge confidence and self-efficacy becomes vital if we are address the gap in the literature in this area, address issues around teacher understanding and therefore help to remove potential barriers in encouraging pre-service teachers to adopt multidiscipline STEM approaches.

Following an evaluation of the intervention described in this paper, it would appear that if teacher educators are to effectively address the issue of self-efficacy development within their training programmes they must consider building in opportunities for mastery experiences. Simple examples such as classroom teaching opportunities which can enable student teachers to experience mastery of aspects such as dealing with children's questions often already exist but may not necessarily lead to the development of confidence and self-efficacy. A consideration of novel approaches and contexts is therefore required. Analysis presented in this paper has led to the following recommendations: -

(1) Providing pre-service teachers opportunities to engage in novel inquiry-based multidisciplinary investigations and to experience mastery of the challenges themselves, before they are required to teach them in the classroom not only results in familiarity with the task but also enables them to have professional ownership of STEM teaching materials and enables them to edit, structure and deliver these as they see appropriate.
(2) The provision of opportunities to teach these materials and to work alongside children as they undertake STEM challenges should be a further consideration as they provide pre-service teachers with mastery evidence in that they are contributing to

children's understanding as well as influencing their enjoyment of STEM and future aspirations in this field. Alongside these aspects it would appear to be important to encourage student teachers to reflect on their development and progress (e.g. through the use of reflective diaries) as this may help to further build concrete evidence of their mastery experiences and therefore contribute to overall feelings of confidence and self-efficacy.

(3) The paired peer model is a meaningful beneficial factor in the development of SMK confidence and self-efficacy. Social models involving peer mentoring to exchange and support the development of SMK, skills and expertise should be built into sustainable models for ITE programmes to develop self-efficacy through collaborative peer, social, constructivist learning and coaching (rather than vertical, hierarchical relationships in a top down approach) where subject and pedagogically focussed discussions and activities can occur within a knowledge exchange framework. Working with a paired peer with complementary skills offers a unique opportunity to student teachers to have their individual training needs met in a personalised and contextualised fashion.

Teacher subject SMK and self-efficacy are not factors that are fixed but instead are developed through experience. Participating in similar novel and collaborative projects early in their career could be crucial in shaping positive dispositions towards STEM subjects for pre-service teachers in the future. With this in mind, it is recommended that teacher educators develop further training activities involving opportunities for pre-service teachers to create, try, implement, and reflect on inquiry-based science lesson plans, alongside social mentoring with peers offering complementary expertise.

5.1. Limitations/recommendations

Despite the potential positive impact participation in the project may have brought to the pre-service teachers, there must remain a note of caution. Due to the low numbers involved, our findings should be addressed with care. Indeed, it cannot be assumed that changes in SMK confidence or self-efficacy will have arisen through participation in the project alone, and may be due to other work completed during university or school-based training, or simply be as a result of the immediacy of having participated. The pre-service teachers also all volunteered to be part of the project and arguably, this may have shaped the research findings given that all were actively interested in STEM education and engineering. It must also be remembered that inconsistencies often occur between teachers' expressed beliefs and their behaviour in the classroom (Van Driel et al., 2001). Results gained from self-reports such as those used in this study should therefore be viewed with hesitation, and any direct impact on changes in classroom practice not assumed. Furthermore, it should also be considered that the evaluative feedback from the pre-service teaches was to be viewed and considered by tutors on their course. Despite assurances to the contrary in the participant information sheets, the pre-service teachers may have been hesitant in reporting negative feedback or to indicate that the project did not have a positive impact on them.

It would be difficult over the short period of this project to assess actual levels of science subject knowledge and wrong to assume that any changes would be solely due to participation in the project. The engineering challenges used were focussed in different scientific fields and concepts making any comparison of subject knowledge acquisition difficult. However, a longer-term study where the pre-service teachers worked on challenges with a comparable content would be useful in helping to assess if participation could also positively influence knowledge acquisition rather than SMK confidence alone. Thoughts about how participation in the project may impact on future practice was a strongly emerging theme from the results with the pre-service teachers indicating that they would adopt a science through engineering approach in the future. A longer-term programme and evaluation would also be useful in assessing lasting changes in teachers' SMK confidence, self-efficacy and to determine if the observed changes would translate into future teaching. For this to occur the project would require scaling up incorporating a more robust pairing mechanism required in order that complementary skills could be assessed more formally and the outcome of the pairings assessed more fully. Ideally, this would be done through the use of reflective diaries coupled with small-scale interviews with the pre-service to provide further insight into which aspects brought about change and to offer suggestions for development of the project. The authors therefore suggest a final recommendation that the research needs to be scaled up with a wider range of participants. More robust mechanisms for pairing could be examined and the outcomes of the individual pairings assessed. Furthermore, stringent analysis of correlations between expressed beliefs in self-reports and classroom practices/ SMK development should be undertaken. This should be done over an extended period of time where the longitudinal impact on practice can be assessed alongside other factors.

Disclosure statement

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Appendices

Appendix 1. Intervention

Intervention to help raise the pre-service teachers' subject knowledge and self-efficacy for teaching engineering to primary-aged children.

Phase 1- Pre Pairing activities

Activity	Content/Purpose
Pre-service teachers. 2 × 2 h seminar sessions	An Introduction to engineering. Assessing and addressing initial stereotypes. An examination of engineering is and what engineers do. An examination of children pre-conceptions, issues around STEM and engineering education and recruitment, children's' STEM choices and aspirations. Researching how such an approach could contribute to a child's science capital and the impact that this may have. Introduction to, and a worked example of the Engineering Design Process. Examining if, why and how engineering should and could be in the primary school curriculum. An exploration of and a worked example of teaching science through engineering, evaluating use of a contextualised, problem solving approach. An introduction to the STEM engineering project.
Engineering undergraduates. 2 × 2 h seminar sessions	An examination of children pre-conceptions, issues around STEM and engineering education and recruitment, children's' STEM choices and aspirations. Reflections on own experiences and motivations. Introduction to relevant theories of learning (inc. constructivism and socio-constructivism, social and science capital) and demonstrations of the application of these theories. An introduction to and worked examples of questioning techniques. An exploration of the requirements of the National Curriculum. Exploration of frameworks on understanding and misconceptions. An introduction to the STEM engineering project. Examination of the science SMK required for each project. Creation of a microteach activity to share, demonstrate and disseminate SMK Delivery of microteach activity to engineer colleagues, evaluation and feedback. Exploration of Health and Safety issues related to the activities and safeguarding in the classroom. Production of a riSMK assessment.

Phase 2- Joint sessions

Activity	Content/Purpose
Knowledge Exchange. Pre-service teachers and undergraduate engineers 3×3 h sessions	Pairings and introduction activities and knowledge exchange interventions to help raise the pre-service teachers' subject knowledge and self-efficacy for teaching science and engineering to primary-aged children. Structured interviews between the pairs with the engineers, examining the nature of role of engineering, the engineers fields of interest/expertise and ways of working. Introduction to the specific engineering challenge to be undertaken by each pair. SMK microteach activities led by the engineers plus subsequent discussions of issues around specific SMK. Joint working through of specific engineering challenges by each pair. Evaluation of the activities and assessment of any potential issues arising Introduction to activity structure and discussions about planning format Discussions about roles, leading and distribution Preparation of plans and resources

Phase 3- In school activities

Activity	Content/Purpose
Pre-service teachers and undergraduate engineers 1.5. days	Introductions with the children- discussion and demonstrations of the engineers roles and the nature of engineering. Question and answer sessions with the children related to this. Explorations of the role of engineers and the nature of engineering (e.g. engineering an envelope, construction of a weight bearing tower). Introductions to the engineering challenges and related stories. Demonstrations, explorations and experimentation related to the science SMK content of the challenges. Introduction and demonstration of the EDP activities (e.g. through a stable table activity). EDP Imagine stage (to offer a range of solutions), EDP ASMK stage (to discover project parameters and to narrow range of possible solutions). EDP plan stage (with demonstration, sharing of ideas and engineer support). EDP Make stage (interspersed with SMK activities when required) EDP Evaluate and Improve stage (continuous testing of products, planned activities to share solutions to problems and ideas for improvement, demonstrating the nature of the way that engineers work) Summing up activities.

Appendix 2. The engineering challenges

Engineering Challenge	Contextualised Pseodo-real-life story	Aspects of Science SMK covered.
High and Dry	Two children live on separate (Greek) islands. They wish to visit each other to spend the day together. They are able to swim to each other's island but want to take some items with them that they do not want to get wet (phones, ipads, books, food, money etc.). Can you help the by building them a product which they will be able to use to transport their belongings and keep them dry whilst they swim?	Floating and sinking Properties of materials Density, weight, mass Buoyancy Forces- gravity, air and water pressure, upthrust, balanced forces. Displacement.
Suck it up!	The class have had a party in their classroom but now the room is very untidy and needs to be cleaned up. Can you design and build a device that will suck up all the small debis?	Electrical circuits Electrical conductors and insulators Switches Propellers/fans and air flow
High Flyers	Two children live opposite each other and have windows (of given dimensions) which face each other. They would like to send messages and small gifts to each other. Can you design and build a glider which will fly the distance between the windows with enough accuracy to reach and fly through the window?	Properties of materials Forces- air resistance, gravity, balanced forces, upthrust, introduction to the science of flight.