Introduction

Background and context

The means by which teacher education systems ensure that secondary science teachers are well-prepared and appropriately trained for their work in science classrooms is a significant topic of international debate (Abell, 2000, 2007). One issue is how best to equip trainee science teachers with the scientific SMK required for teaching, given evidence that possession of "good" SMK influences teacher effectiveness positively (Abell, 2007, Geddis, et al, 1993; Lederman et al, 1994). This paper contributes to the discussion by offering perspectives from pre-service science teachers' ("trainees") experiences of training on an intensive, full-time course taking place over an extended academic year. Specifically, this paper explores the extent to which trainees' subject matter knowledge (SMK) in science influences their self-confidence for teaching: trainees are graduates in specific science disciplines, such as biology, chemistry, physics, astronomy, geology and others, but are required to teach all sciences to 11-14s while training and, often, while working in UK state-funded secondary schools. An investigation of sources employed by trainee science teachers to develop their SMK for teaching is reported, together with the potential impact SMK may have on confidence in relation to their classroom practice. The study thus contributes to discussion of the role SMK plays in teacher development.

The work also contributes to the ongoing debate as to whether science should be split into its internal disciplines for teaching purposes. By way of illustration, discussion is ongoing in the UK, for example, as to whether or not physics should be taught by specialist physicists, chemistry by chemists and biology by biologists. For example, a lobbying group, the Campaign for Science and Engineering in the UK (CaSE) argues:

"Children need to be taught by specialist [science] teachers. Teachers' qualifications predict teaching quality and are the second greatest predictor of performance in physics after pupil ability" (CaSE Opinion Forum, May 2007)

Similarly, the Royal Society of Chemistry (RSC), a professional organisation representing chemists internationally, states:

"The best teachers are those who have specialist subject knowledge and a real passion and enthusiasm for the subject they teach…. The RSC believes that young people deserve to be taught the sciences by subject specialists" (Royal Society of Chemistry, 2004)

These views are set against a factual background showing considerable imbalance in the proportions of science teachers with physics, chemistry and biology degrees. A 2006 UK Government report showed that 25% of UK science teachers (in a sample of 2756) hold degrees in biology or biology-related subjects, compared to 16% with chemistry degrees and 10% with physics degrees. Of the remainder, 47% hold degrees in other science subjects or possess teaching qualifications in general science, while 2% have no science degree (Moor, Jones, Johnson, Martin, Cowell and Bojke, 2006). Social status also plays a part: in schools with higher than average examination results and lower than average numbers of children receiving free school meals (a standard indicator of high social need) more science teachers held specialist degrees in physics, chemistry and biology (Moor et al, 2006).

Hence, establishing factors shaping how trainee science teachers teach within and outside their specialist subjects would contribute to enhancing science teacher education.

The study is situated in the Shulman paradigm in which subject matter knowledge (SMK) is perceived as separate from but essential to teachers' pedagogical content knowledge (PCK). Shulman (1986a, b) proposed that teachers "transform" SMK for their students using PCK, a powerful model that has been re-interpreted widely (for example, Marks, 1990; Magnusson et al, 1999; Carlsen, 1999).

This paper takes the view that in describing a lesson as "successful", the teacher's ability to transform SMK is significant. Evidence presented below shows that trainee science teachers' perceptions of their teaching as "successful" varies: some appear to consider a lesson as a "success" when they transmit knowledge, expressing confidence in the sense of personal survival when they understand the SMK for a specific lesson and can answer subject-related questions. Others take a "transforming" approach, perceiving "success" as finding good activities that help children learn, placing personal mastery of SMK as a secondary concern. Trainees' development of SMK for personal "survival" or "transformation" may vary according to whether teaching takes place within and outside subject specialism. Given the accepted wisdom that science teachers teach their specialisms most successfully, a reasonable hypothesis is that within specialism lessons would generate fewer trainees relying on "survival" and more "transformation". Data are presented that contradict this, suggesting that in the initial stages at least, some trainees were more confident and taught more successful lessons when teaching outside their specialist subjects.

The English and Welsh initial teacher education context

The study took place in a University in northern England, using trainees attending an initial teacher education (ITE) course, the "Postgraduate Certificate in Education" (PGCE). Obtaining a PGCE constitutes the major route into secondary school teaching. The PGCE is an intensive programme requiring nine months of full-time study from September – June. The course combines school-based practice (24 weeks) and Higher Education Institution (HEI)-based work (12 weeks). All participants are graduates with a Bachelor's degree in a subject linked closely to a National Curriculum (DfES, 2004) subject. In science, trainees' degree subjects dictate their teaching subject specialisms of chemistry, physics, or biology. A majority of trainees have backgrounds in biology or biology-related subjects, and little or no post-16 education in either physics and/or chemistry. Trainees' minimum age is 21, so at least five years and for many, ten years have passed since these sciences were studied.

The National Curriculum for science stipulates the content of 11-16 science courses taught in state-funded secondary schools. Pupils' learning is measured by tests taken at age 14 and 16. Hence, teaching divides into topics for 11-14s (Key Stage 3) and 14-16s (Key Stage 4). To deliver the curriculum, school science teachers write "Schemes of Work" (SoWs), giving precise details of lessons, often based on published materials and textbooks. Teachers are expected to teach all aspects of science to 11-14s and, frequently, 14-16s regardless of their subject "specialism"; hence, this is also expected of trainees. During the school-based practice, trainees teach 11-16s and, exceptionally, 16-18s in two different schools located within 50 miles (80 km) of the university. Trainees are often expected to follow schools' defined schemes of work, but may have freedom to develop their own lessons or parts of lessons. Trainees participated in forty-five hours of HEI-based sessions to develop their SMK for teaching specific science topics at Key Stage 3 and Key Stage 4. Topics included electricity, forces, chemical reactions, energy, waves, ecosystems, the genome, Earth and space, substances and investigations. Materials for use when teaching were provided with details of experiments and potential misconceptions. Trainees were introduced to science education research through these sessions and also by preparing a written assignment.

Literature review

The role of SMK

The notion that possession of good SMK is an essential component of effective teaching has been demonstrated in a number of research studies, including those by Shulman (1986b, 1987) and those reviewed by Abell (2007) and Gess-Newsome (1999). A useful summary of the position and value ascribed to SMK in teaching is provided by Carré (1998):-

"The more you know about science, the more you will be able to provide a framework to help children think in scientific ways; in so doing you will also represent the subject with integrity" (p 103)

Hashweh's (1987) work with six experienced science teachers offers evidence for this. He found that "knowledgeable" teachers had more detailed knowledge of the topic being taught, demonstrated wider knowledge of the same subject, and were more readily able to relate a topic to other aspects of the subject. More specifically, Hashweh reported that possessing good SMK positively affected a range of aspects considered essential to good science teaching. These included teachers' abilities to transform material for delivery in lessons by planning novel activities and their responses to critical incidents in the classroom. Knowledgeable teachers posed higher cognitive level questions while "unknowledgeable" teachers asked for recall and relied heavily on textbook information. Sanders, Borko and Lockard (1993) followed the teaching of three experienced secondary science teachers working within and outside specialism. Although general pedagogical practices were similar in both domains, when teaching within specialism teachers talked less, involved students more and selected "riskier" activities.

An exploration of research relating to the precise role played by SMK in teacher development yields a varied picture. De Jong (2000) and van Driel et al (2002) provide evidence that good SMK helps trainees be more readily aware of students' difficulties, a key aspect of Shulman's model for PCK. In a highly specialised but extremely thorough study, Davis (2003) indicates that good SMK helps trainees select appropriate instructional strategies, also a feature of Shulman's PCK model. Thirdly, Markic et al (2006) indicate that SMK contributes to teachers' orientations towards teaching and beliefs about science. All these factors are likely to vary according to whether trainees are working within and outside their subject specialisms – for example, a physics specialist teaching biology topics may find it more difficult to select appropriate instructional strategies and be less aware of students' difficulties than a biologist teaching the same topic. As an indication of the possible effects of outside specialism teaching, Carlsen's (1993) study of four trainee biology teachers found that when teaching an unfamiliar topic, participants tended to talk more often, for longer periods of time, asked questions frequently and relied heavily on low cognitive level questions.

Misconceptions about science concepts are a significant concern for science education researchers. In terms of educating science teachers, learning outcomes related to misconceptions achieved by trainees may differ, depending on whether a lesson is being taught within or outside specialism. A biology lesson taught by a physicist may be less satisfactory than the same lesson taught by a biology specialist, as the physics trainee may have similar misconceptions to the children being taught. Sanders (1993) explored the views of South African biology teachers about respiration, finding that many seemed to hold misconceptions about basic principles within this topic. However, the study did not distinguish between specialist and non-specialist biology teachers.

Besides these specifically SMK related issues, other research evidence indicates that specialised support helps trainee science teachers develop positively (Luft et al, 2003). In the present system, each trainee teacher is provided with an experienced science teacher as a "mentor" to assist them on teaching practice, as well as a university tutor. Mentors help trainees gain access to additional support within school science departments and hold regular (usually weekly) one-to-one meetings with trainees. Despite mentors' and tutors' good intentions, Youens and McCarthy (2007) found that trainees tend not to use mentors and university tutors as sources for SMK development, due to awareness of their roles in assessing progress. Trainees think that asking for help may imply they are failing. This perception may impact on trainees' preparation for and subsequent success in within and outside specialism teaching.

Science teachers' perceptions of success, self- confidence and self-efficacy

The influence of specialized support on teachers' confidence or "efficacy" has been investigated by Hoy and Spero (2005), who showed that positive effects are seen where this is effective. However, Youens and McCarthy's (2007) work shows that these may be negated in situations where a dual role is perceived –mentors and university tutors are involved in reporting on trainees' progress, controlling whether they "pass" or "fail", as well as providing support. As mentioned above, the assessment role appears to dominate, as trainees forgo asking for support, in case this indicates weakness on their part. In which case, it would be valuable to know what sources of SMK are used by trainee teachers and why these are selected, given that obvious collegial support is, at least by some, cast aside. Further, any differences between SMK sources for within and outside specialism teaching may exist and these may impinge on trainees' success in teaching and perceptions of success.

The role of support and teacher self-confidence emerged as factors influencing success in teaching science among nine novice primary school teachers studied by Appleton and Kindt (1999). This study makes an interesting and significant connection between weak subject matter knowledge and self-confidence, reporting that teachers lacked confidence to teach science and that this seemed to be associated with limited background knowledge (p 160). Teachers' self-confidence was negatively affected by believing that they had to be competent to answer children's subject-related questions. In contrast to Youens and McCarthy's (2007) findings, once beyond the bounds of a training experience, the teachers in this study found collegial support valuable, providing, for example, the confidence to try new activities and teaching strategies and support for planning science teaching.

Borko, Lalik and Tomchin (1987) examined trainees' conceptions of "successful" teaching, comparing journal writings of "stronger" and "weaker" novice teachers. They found that although trainees generally agreed about what constitutes "successful" teaching, differences were observed regarding "unsuccessful" teaching. By "successful", trainees indicated they meant using creative and novel activities, generating a variety of experiences for their students. Preparation of lessons with these characteristics involved going beyond the prescribed curriculum and associated tasks. Trainees emphasized trying out new ideas, maintaining pace and handling behaviour issues effectively. When describing "unsuccessful" lessons, weaker trainees focused more on behaviour issues and planning, while stronger trainees focused on a lack of creativity on their part.

Teachers' beliefs about the potential influence of specific environmental factors on their science teaching were investigated by Lumpe, Haney and Czerniak (2000). These authors developed a "Context Beliefs About Teaching Science" (CBATS) instrument designed to assess the extent to which teachers beliefs about aspects of their work were positive or negative. They report that more positive beliefs emerge among more experienced teachers, describing a majority as holding "robust, modest and tenacious" belief patterns (p 285). These sustain teachers when working in frustrating circumstances, providing a structure that helps them function effectively in the classroom. A minority were found to be "vulnerable, fragile and self-doubting". The authors comment that teaching may select against such weak profiles, and teachers possessing these belief systems may leave the profession at an early stage.

Given these previous studies, the possibility exists that trainees experience different levels of confidence for teaching within and outside specialism, as well as using different sources to develop their SMK.

Hypothesis and research questions

Hence, this study investigates:

- What sources do trainee science teachers use for developing their subject matter knowledge for within and outside specialism teaching while on a ten month postgraduate teacher education course?

- To what extent is the confidence of trainee science teachers influenced by teaching within and outside their specialist subjects?

Methodology

The design of the study follows the tradition of interpretative and descriptive qualitative work (Merriam, 2002), although data were collected using both interviews and questionnaires. These methods gave the best overview of trainees' experiences, providing an insight into the widest possible range of opinions and views within this context. The interviews were designed to validate questionnaire responses.

Data were analysed to characterise trainees' attitudes and confidence relating to SMK for within and outside specialism teaching. Categories emerged from the data – a combination of responses to open questions and Likert scale statements together with interview responses revealed specific characteristics. These are discussed in detail below.

The questionnaire

The questionnaire, devised for this study (Appendix 1) comprised three probe types:-

- Open questions (numbers 2 and 3) probed trainees' sources of SMK for preparing science topics for teaching within and outside their specialist subjects

- A closed question (number 4) invited trainees to rank preferred sources of subject knowledge from a pre-prepared list

- Four sets of paired statements explored trainees' thinking about SMK and teacher confidence using a five-point Likert scale. The pairs were named "Attitude" (A), "Preference" (P), "Confidence"(C) and "Handling questions" (H). For reference purposes, these letters are shown against the statements in the questionnaire (Appendix 1).

The components of the questionnaire were validated by discussion with colleagues.

In addition, background information such as trainees' education, age and gender were collected.

The interviews

Individual interviews of approximately 30 minutes each were conducted using a semi-structured protocol. The interviews collected data relating to the topics trainees had taught; sources used to develop SMK needed for teaching within and outside specialism; trainees' awareness of the impact of their preparation on achievement of intended learning outcomes; and the extent to which their modes of subject matter knowledge acquisition and lesson preparation changed during the PGCE course.

Questionnaires were administered in April 2006 and April 2007 after completion of all HEI-based sessions and towards the end of the main teaching placement. Interviews were conducted in June 2006 and June 2007 when all parts of the course had been completed.

The sample

A total of 71 trainees completed the questionnaire. These comprised twenty-eight respondents from the 2005 – 2006 cohort and forty-three from 2006 – 2007. Maxima of forty (2005- 2006) and fifty-two (2006-2007) were possible – absences and fall-out from the course on the day of data collection account for discrepancies. For reporting purposes, all respondents are treated as one group – this is reasonable given that both cohorts had as identical experiences as possible.

Twelve trainees were interviewed, divided 5:7 between the 2005- 2006 and 2006 – 2007 cohorts. The trainees were volunteers, but care was taken to ensure participants were as far as possible representative of all respondents in terms of subject specialism, age and gender.

Data analysis

Each questionnaire was given a code number. The same codes were used to identify interviewees to check for triangulation of responses between interview and questionnaire data.

Background information

Trainees' background information was counted and used to generate the data in Table 1.

Questionnaire

Questionnaire responses were edited to establish the extent of completion and examined for any inaccuracies. All 71 trainees responded to the open questions, the closed question and paired statements. Ten trainees mis-interpreted the ranking for the closed question (number 4 in Appendix 1) so their responses were excluded from the data (see Table 2, Total)

Open question responses (questions 2 and 3) were coded by the researcher. A coding frame was used to establish the range of responses offered. The same frame was applied to questions 2 and 3 (see Appendix 1). Responses were grouped by:-

- Trainees' subject specialism (drawn from background information)
- Trainees' chosen topic
- Trainees' stated preparation strategy/ies
- Other information provided by the trainee

Responses from two trainees who gave only general comments relating to their school circumstances and no information about preparation strategies were excluded. Thus, Table 3 presents data from 69 trainees.

The preparation strategies described were grouped into the categories shown in Table 3. Other information, most often about teaching, included phrases such as "tried to break down the information into key sentences".

For example, Question 2 required trainees to name topic they had taught within specialism and describe SMK preparation. Three biology specialists named "Microbes and Disease" as their topic. Two trainees cited "knowledge from degree" and one "knowledge from own University research". These three responses appear in Table 3 as "Prior knowledge from University degree or job".

Question 3 required trainees to name a topic they had taught outside specialism and describe SMK preparation. Two biology specialists and one physics specialist named "Chemical reactions". Their SMK strategies, with Table 3 "SMK source" in parentheses were: two cited teacher involvement (School colleague or other trainee teacher), two used the internet (Internet), two used school textbooks (Textbooks, school resource packs, teacher materials), one looked at an examination paper for the year group (Formal documentation), and two tried out experiments prior to the lessons (Other source).

Responses to the closed question, number 4 were counted and recorded against the suggested strategies. These data are presented in Table 2.

The paired statement analysis was done by counting systematically through all the responses, noting the code numbers and background information for each respondent for each pair. Scores 1 and 2 were summarised as "Agree" while 4 and 5 became "Disagree". This generated a series of sub-groups for each response pair (see p 15 – 18). The background characteristics were examined and compared with the data for the whole cohort (Table 1). Where marked differences were observed, these were noted in the results.

For example, in response to the "Preferences" pair, 8 trainees responded "agree" (Likert score 2 on the questionnaire) or "strongly agree" (1) to "I prefer to teach topics in my specialism" and were "neutral" (3) or disagreed (4, 5) with "I am pleased to teach topics in all areas of science". Analysis of the background information for this group showed that these respondents divided equally into male and female, had an average age of 29 and all except one held degrees at the standard of 2:2 or better. This sub-group expressed "specialist" views, but revealed no characteristics that were markedly different from the whole group. Hence, the existence of the group was noted (see p 14) but no further comments could be made.

Analysis of the "Confidence" pair showed a sub-group of 14 trainees who disagreed with "I am less confident when I teach outside my specialism" (Likert score 4 or 5) and agreed with "I do not need to teach my specialism to feel confident as a teacher" (1 or 2). These trainees had two background characteristics that differed from those of the whole group. Six were aged 31 or over, comprising a significant proportion of the 16 trainees in this age group shown in Table 1. Two others were aged 28 and 29. Four trainees (28%) were aged 21 -25 compared to 58% of the whole cohort. Thus, the overall age profile of this sub-group is higher than that of the whole cohort. Ten of the fourteen, 71% were female (61% for the whole cohort). Seven held degrees in the two highest classifications "1st" and "2:1", a figure similar to that for the whole cohort. Consequently, comments to this effect are made in the results section (p 15).

Interviews

Interviewees were volunteers who knew the researcher as a PGCE course tutor. To ensure comparability of responses, a standardised set of questions (LeCompte and Preissle, 1993) was prepared (Appendix 2). This was sent in advance to participants by email. No potential interviewee refused to attend having seen the questions. Interviewees were invited to bring documentation such as lesson plans and lesson evaluations for discussion. These were considered once responses to the standard questions were concluded.

Five questions triangulated responses to questionnaire questions (Q) and/or paired statements (P, followed by reference letter) as follows:-

Interview	Q1 supports questionnaire	Q1	
	Q2	Q4	
	Q3	Q2, 3	PA, PC
	Q4	Q2, 3	PP, PH
	Q5	PP, PH	

The purpose of question 6 was to illustrate the extent to which trainees' practice had altered during the PGCE course and to serve as a means of validation: two months had elapsed between collection of questionnaire and interview data. Indicative responses to this question are provided on p 23. Ten trainees referred only to their planning and preparation "speeding up" as the course proceeded, noting no other changes. Two trainees (see p 23) specifically said no changes had occurred.

Interviews lasted about 30 minutes each. Follow-up questions were posed in addition to the standard ones where necessary to illuminate or clarify answers or to draw out more information when a trainee seemed shy or reluctant. Hence the format could in practice be described as "semi-structured", as these varied according to the interviewee.

The recorded interviews were transferred to ATLAS for analysis. Pseudonyms were devised for each trainee at this stage. A transcript was prepared from each interview. After transcription trainees were matched against their questionnaires. Consistently excellent correspondence could be ascertained between interview and questionnaire responses. To illustrate this, two questionnaire response profiles are provided:-

Matthew, aged 38, Male, Physicist, 1st class degree

Questionnaire Q2 response:- Light – I used subject revision guides to establish what the content should be. My subject knowledge was already adequate

Questionnaire Q3 response:- Cells – I read revision guides and subject books.

Questionnaire Q4 response:- My strategies were the same apart from I researched in more depth the cells topic

Paired statement responses:-

Attitudes:	Agree with "I enjoy learning…"	Disagree with "I find it difficult…"
Preference:	Agree with "I prefer to teach…"	Disagree with "I am pleased to teach…"

Confidence: Agree with “I am less confident ..” Disagree with “I do not need to teach…”
Handling questions: Agree with “I can handle..” Disagree with “I am nervous…”

Matthew’s responses indicate he may be anxious about teaching outside specialism (see p 17). His views about outside specialism teaching expressed at interview are stated on p 18.

Simon, aged 28, Male, Chemistry, 2:2 degree with PhD

Questionnaire Q2 response: Particles – Looked at textbook, school’s scheme of work, resources from HEI-based session, internet

Questionnaire Q3 response: classification – Same as above (ie as Q2)

Questionnaire Q4 response: I used [the] same strategies because [I] drew on large area of resources and ideas. [I] prepared in the same way for topics I know about and topics I don’t.

Paired statement responses:-

Attitudes: Agree with “I enjoy learning…” Disagree with “I find it difficult…”
Preference: Disagree with “I prefer to teach…” Agree with “I am pleased to teach…”
Confidence: Disagree with “I am less confident ..” Agree with “I do not need to teach…”
Handling questions: Agree with “I can handle..” Disagree with “I am nervous…”

Simon’s responses indicate he is confident teaching all aspects of science (see p 17). His views about teaching outside specialism are on p 20.

Results

Trainees’ backgrounds

[Insert Table 1 about here]

Table 1 provides information about the gender distribution, degree class[1], age and science subject specialism of the respondents.

The samples were representative of the full cohorts, being skewed approximately 60:40 towards females. Most trainees were born in North East England and Scotland. Four trainees born

[1] Degree class is divided into four categories of “Honours”: the highest achieving students, usually around 10% of a cohort, are awarded “First” (1st) class degrees. These students normally score around 70 – 75% in their final examinations. About 40% are placed in the next category, “Upper Second” (2:1) class. About 30% gain “Lower Second” (2:2) class degrees. About 20% are awarded “Third” class honours. Those whose work is deemed not of Honours standard may be awarded “Ordinary” or “Pass” degrees.

outside the UK were classified formally as “ethnic minority” trainees. Eight participants who completed the questionnaire did not complete the successfully for different reasons.

Degree subject is the key indicator used to decide trainees’ science specialism as physics, chemistry or biology. Trainees’ degree subjects are broad-ranging: data indicate that about 65% of respondents were “biology specialists”, holding degrees in biology (16%) or “biology-related” subjects (49%). The latter included graduates in genetics, ecology, biomedical sciences, aquatic / marine bioscience and physiology. Nine (12%) trainees held degrees in chemistry, while a further eight (11%) were classified as “chemistry-related”; this group included biochemists, geologists, environmental chemists and pharmacologists. Eight trainees held degrees physics or physics-related subjects, such as astronomy, mechanical engineering and optometry.

Degree class is widely respected as an indicator of the quality of trainees’ science specialist knowledge. These trainees are regarded as “academically well-qualified”: Table 1 shows that about 54% held Upper Second (2:1) or First Class (1^{st}) honours degrees, these being the two highest degree classifications possible, while a further twenty-one held Lower Second (2:2) class degrees. Thus, overall around 83% of respondents held “good” degrees. Nineteen also held Masters or Doctorate qualifications in science. One held a Masters degree in Law. Possession of a “good” degree means that a trainee would respond correctly to GCSE (General Certificate of Secondary Education: the Key Stage 4 examination taken at age 16) questions in their specialism.

Trainees’ average age was 27. Around 58% were aged 21 – 25. For this sub-group, teaching is their first career choice. The remainder comprise those changing career, such as post-doctoral scientists, science graduates who have worked in non-science fields and parents returning to work.

Preferred sources of SMK for teaching

[Insert Table 2 about here]

In responding to the questionnaire, trainees ranked a pre-prepared list of possible SMK sources from 1(most preferred) to 10 (least preferred). These data indicate strong preference for school-based or school-oriented material, reliance on note-taking and reading. HEI-based teaching sessions, misconceptions and science education research literature received low rankings. Ten trainees did not provide sufficient information to be included.

SMK sources for teaching within and outside specialism

Open questions prompted trainees to choose one topic each from within and outside their specialisms that they had taught and describe sources used to prepare the SMK required. Table 3 summarises the SMK sources trainees cited in their responses. The figures represent the numbers of trainees citing each source. Most trainees cited more than one.

[INSERT TABLE 3 ABOUT HERE]

Within specialism teaching SMK preparation

Table 3 indicates four main sources of SMK - the internet, textbooks, prior knowledge and formal documentation – were used for within specialism teaching preparation. Comments emphasised trainees' sense of "already knowing" the topic, implying little work was needed, for example:-

> "I knew it and only had to skip through the Key Stage 3 revision book, ie. 5 mins" (Chemist)
>
> "Forces – looked at QCA[2], school and exploring science SoWs and tests to come up with learning objectives and teaching scheme… otherwise did not need to think about own subject knowledge" (Physicist)

Three trainees explicitly stated they consulted no additional SMK sources, relying entirely on prior knowledge.

The 19 trainees citing "textbooks" regarded these as low level material, of whom six described this choice as "background reading", or "refreshing knowledge", for example:-

> "Cells. Background reading which brought back what I already knew … I already felt quite confident with the topic" (Biologist)

Five used revision guides (classified as "other) to check the level of knowledge required by their students, for example:-

> "Light – I used subject revision guides to establish what the content should be. My subject knowledge was already adequate" (Physicist)

Five trainees believed they had the necessary subject knowledge, but wanted to find good resources or explanations to use in teaching, for example:-

> "Acids and alkalis – [I] looked at how to describe ideas using simple vocabulary" (Chemist)
>
> "Variation – I.. researched for novel activities…." (Biologist)

These trainees seem aware of transforming SMK to pedagogical content knowledge (PCK).

Table 3 indicates that few trainees prepared for within specialism teaching by seeking colleagues' advice, consulting misconceptions or science education research literature or testing out practical experiments prior to lessons.

Outside specialism SMK preparation

Table 3 shows that a more intense pattern of SMK sources emerges for outside specialism preparation. School colleagues and textbooks were consulted by about half of respondents. The

[2] The QCA is the Qualifications and Curriculum Authority, the organisation responsible for setting examination standards. The QCA has produced a scheme of work for teaching KS3 used by some schools. www.qca.org.uk

internet and formal documentation were also popular. The range of sources reflects trainees' awareness of SMK weaknesses and perceived need for more detailed preparation, for example:-

> "Electromagnetic spectrum – [I] read around the subject and to a higher level than I was required to teach. [I] prepared an extensive lesson plan with difficult concepts fully written out" (Biologist)

The role of school colleagues in helping trainees prepare for outside specialism teaching is apparent, for example:-

> "Environments – had long conversations with other teachers…" (Physicist)

> "Radiation – [I] spoke to the physics teacher (he knows everything)" (Biologist)

> "Gravity and Space - ….Teachers at school and technicians were very helpful" (Chemist)

Trainees using textbooks did so to learn the information necessary, rather than to check the level of understanding required, for example:-

> "Paints and pigments – [I] read over student textbook then looked in A level book to improve higher knowledge then researched on internet" (Biologist)

The increase in "Other" sources for outside specialism SMK arises from trainees stating that they practiced experiments before lessons, or asked for help in setting up equipment.

Comparing SMK sources for within and outside specialism teaching

Table 3 shows that about 50% of trainees actively seek colleagues' advice in preparing outside specialism lessons. SMK preparation for within specialism teaching is characterised by trainees relying heavily on prior knowledge and not seeking advice or testing experiments prior to teaching.

About two-thirds of trainees expressed clear differences in their approaches to within and outside lesson preparation, for example:-

> "My biology topics are fairly clear in my mind and so I do not need to look at basic knowledge … with Chemistry I am not sure of my basic knowledge and must look at the topic as though I am teaching myself." (Biologist)

> "I needed to make sure I was prepared for any additional questions students may ask" (Biologist)

About ten trainees indicated that outside specialist subject lessons were sometimes "easier", for example:-

> "Non-specialism takes longer [to prepare] but is sometimes easier to teach as you don't have the same extent of knowledge" (Biologist)

This response, found also at interview (see below, p 16) suggests that possession of too much subject matter knowledge could be problematic. Outside specialism teaching meant that trainees taught what they learned, resulting in more clearly focused lessons than those taught within specialism.

Other emerging issues relating to outside specialism teaching included one trainee who sought to avoid misconceptions:-

> [Outside specialism] – emphasis on accuracy and avoidance of misconception perpetration" (Biologist)

and this trainee who explicitly stated she prepared to enhance her confidence:-

> "[I did] far more preparation for the physics topic to feel more secure and confident" (Biologist)

Two trainees stated specifically they used the same preparation method throughout, for example:-

> "I used similar strategies as I find them most effective to refresh my knowledge and ensure my understanding" (Biologist).

The extent to which trainees' confidence for teaching relies on subject matter knowledge

[Insert Table 4 about here]

Trainees' responses to eight statements scored using a five-point Likert scale are summarised in table 4. The statements were paired to permit exploration for consistencies in response patterns: one pair each investigates trainees' **preference** for teaching within and outside specialism; their **confidence** for teaching; the extent to which trainees believe they can handle students' **questions;** and trainees' **attitudes** towards SMK.

Detailed data relating to combinations of responses are presented below. For this purpose, the scale has been summarised to three points by adding "strongly agree" to "agree" and "strongly disagree" to "disagree", with neutral in the centre. The words "agree" and "disagree" are used to express extremes. All 71 trainees responded to all statements.

Preferences for within and outside specialism teaching

Two statements, "I prefer to teach topics in my specialism" (abbreviated to "prefer specialism") and "I am pleased to teach topics in all areas of science" (abbreviated to "all science") assessed trainees' preferences. A trainee preferring in-specialism teaching may respond positively (strongly agree/ agree) to the first statement and negatively (disagree/ strongly disagree) to the second; vice versa for a trainee preferring to teach all sciences.

Table 4 shows that around 56% (total of “strongly agree” and “agree”) of respondents prefer to teach their specialism, while over 80% (total of “strongly agree” and “agree”) say they do not mind teaching all aspects of science. However, these data mask underlying response patterns. These are analysed next. Four clear patterns emerge:-

32 (45%) Trainees agreed with both statements
15 (21%) Trainees disagreed with “prefer specialism” and agreed with “all science”
12 (17%) Trainees were neutral to “prefer specialism” and agreed with “all science”
8 (11%) Trainees agreed with “prefer specialism” and disagreed or were neutral to “all science”

Four trainees’ responses did not fit these categories.

Trainees agreeing with both statements are not necessarily inconsistent – they may be saying that although they prefer to teach within specialism, they are also pleased to teach all topics. They can work on SMK and may enjoy this. Around 21% claim preference for teaching all science topics. This group could be described as “generalist” in outlook. The twelve trainees neutral to the “I prefer to teach…” statement could also be “generalist”, although they express their preference less strongly. Finally, a small sub-group of “specialists” exists; these trainees express strong preference for within specialism teaching.

Confidence for teaching

The statement pair exploring trainees’ confidence for teaching was “I am less confident teaching outside my specialism” (“less confident outside”) and “I do not need to teach my specialism to feel confident as a teacher” (“don’t need specialism”). A trainee with good self-confidence may respond negatively to the first statement (strongly disagree or disagree) and positively to the second. A more anxious trainee may state the reverse.

Table 4 shows that 53% respond “strongly agree/ agree” to “less confident outside”, while twelve disagree. This significant minority express confidence in their ability to teach outside specialism. However, in a seemingly contradictory fashion, about two-thirds agree or strongly agree with “Don’t need specialism”, implying that they can teach anything. Closer inspection of underlying response combinations reveals these pairings:-

14 (21%)Trainees disagreed with “less confident outside” and agreed with or were neutral to “don’t need specialism”

9 (12%) Trainees were neutral to “less confident outside” and agreed with “don’t need specialism”

25 (35%)Trainees agreed with both statements

5 (7%)Trainees agreed with “less confident outside” and disagreed with “don’t need specialism”

7 (10%)Trainees agreed with “less confident outside” and were neutral to “don’t need specialism”

Eleven trainees’ responses did not fit into these categories.

The disagree / agree sub-group (14, 21%) could be labelled “super-confident”, as they state that outside specialism teaching does not affect their confidence. Examining these trainees’ backgrounds shows that seven have degrees in the highest two classes (1st or 2:1) or hold a higher degree, while ten are female. The average age is 31: six are aged 31 or over. Tentatively, “super-confident” trainees could be academically well-qualified females older than the average age of the cohort.

Those agreeing with both statements (25, 35%) seem to offer contradictory statements. Without going back to every trainee, it is difficult to comment as to why this is the case. However, interview data suggests that despite feeling less confident or apprehensive about teaching outside their specialism, this can be handled by working on their SMK (see p 16, Views about teaching within specialism). Hence, trainees could respond positively to “I do not need to teach my specialism…”, while at the same time feeling less confident. This sub-group are tentatively labelled “working-confident”.

Twelve trainees agreeing with “less confident outside” could be described as “anxious”. These split 50:50 by gender and degree class, with six possessing 1st or 2:1 degrees. The average age is 25, below that of the whole group, although four trainees were aged 30 or over. Reasons for trainees’ lack of confidence are unclear, but collectively their backgrounds differ from “super-confident” and “working-confident” trainees.

Handling SMK-related questions

Statements investigating trainees’ attitudes towards handling SMK-related questions were: “I can handle the situation if I am asked difficult questions outside my specialist area” (“I can handle”) and “I am nervous that I will be asked a question I cannot answer” (“I am nervous”). Anecdotally, handling subject-related questions causes anxiety among many science trainees, particularly in the early stages. A trainee able to cope with these may respond positively (strongly agree / agree) to the first statement and negatively (strongly disagree/ disagree) to the second. A more nervous trainee may respond oppositely.

Table 4 shows thirty-two trainees felt nervous about being asked a question they could not answer (strongly agree /agree), while fifty agreed or strongly agreed with “I can handle”. Overall, a majority of respondents appear confident about difficult questions, perhaps accepting that nerves are to be expected. These underlying response combinations were found:-

34 (48%)Trainees agreed with “I can handle” and disagreed or were neutral to “I am nervous”
17 (24%)Trainees agreed with both statements
15 (22%)Trainees agreed with “I am nervous” and disagreed or were neutral to “I can handle”

Five trainees disagreed with “I am nervous”.

These figures suggest that about 48% express confidence in their ability to handle questions outside their specialist area and feel little or no nerves about being asked questions they cannot answer. About one-quarter (24%) seem to regard nerves as “part of the game”, responding positively to both statements. About 22% seem to have a more “anxious” disposition, admitting to feeling nervous and not being able to handle difficult questions. Background information shows sixteen of the thirty-four trainees (47%) feeling most confident at handling questions are male, skewing this sub-group away from the cohort’s 60:40 split. Twelve of the fifteen trainees (75%) feeling least confident were female, a skew in the opposite direction.

Attitudes to SMK

The statements exploring trainees’ attitudes to SMK were “I find it difficult to develop my subject knowledge outside my specialist area” (“I find it difficult”) and “I enjoy learning new subject knowledge outside my specialist area” (“I enjoy learning”). A trainee with a positive attitude towards outside specialism teaching may respond negatively (strongly disagree / disagree) to the first statement and positively (strongly agree / agree) to the second. A trainee feeling uncomfortable learning new SMK may respond oppositely.

Table 4 shows highly polarised responses to these statements. About 79% strongly disagree / disagree with the first and 83% strongly agree / agree with the second. Although this is a strong indication that the majority of respondents have positive attitudes towards acquiring new SMK, examination of underlying response patterns shows that small sub-groups showing slight variations exist:-

50 (70%) Trainees agreed with “I enjoy learning” and disagreed with “I find it difficult”

10 (14%) Trainees were neutral to “I enjoy learning” and were neutral to or disagreed with “I find it difficult”

3 Trainees agreed with both statements

2 Trainees were neutral to “I enjoy learning” and agreed with “I find it difficult“

Six trainees’ responses did not fit into these categories.

Perhaps most interesting to note is the small number of trainees (3 + 2, last two categories) whose responses suggest they find learning new SMK is difficult: three were females aged over 30 and three held 2:2 degrees, while the remaining two held 2:1s. This sub-group are noticeable amongst the overwhelmingly positive responses.

Semi-structured interview data

The twelve interviews indicated the impact perceived by trainees of SMK on their teaching, as well as validating responses found in the questionnaires. The interviewees were slightly more skewed towards males (6/12, 50%) and chemists / physicists (5/12, 42%) than the whole cohort. Interviews explored how trainees perceived their SMK and confidence as a teacher impacted on students' learning. Trainees' voices are reported verbatim, although colloquial and dialectical expressions have been modified to ease comprehension. Names used are pseudonyms. All interviewees completed the PGCE course successfully but with differing teaching abilities. In reporting their viewpoints, reference is made to interviewees' Likert scale responses, hence references to "super-confident", "working-confident" and "anxious".

Views about teaching outside specialism
Three main viewpoints corresponding to questionnaire categories (p 12) were apparent. Matthew, an "anxious" trainee according to his confidence responses, said this about teaching outside specialism :-

> "In physics when I felt the [children] weren't grasping it [the topic] I could tackle it from a different angle by thinking myself, 'How's the best way to put this across?' and going down a different route. That was very limited for me with biology ….I wouldn't have had the knowledge to do that. If it had happened, I would have had to extend into a different lesson, and gone away, thought about it and brought it back in another lesson." (Matthew, physicist)

Daniel and Mary reported differences in the ease with which they prepared for teaching in the two domains. Their confidence responses corresponded to the "working confident" category:-

> "I felt I could prepare resources for my specialism much easier, and I was a lot less confident at trying new things, so for chemistry I stuck exactly to what the Scheme of Work gave me … with biology [when I thought] " I don't agree with that", it was much easier to change things." (Mary, biologist)

> "I was a lot less creative with biology and physics – that went down to confidence in the material… I went down traditional lines… I didn't tend to [experiment] unlike my chemistry where I liked to [be] more creative."
> ("Daniel", chemist)

These trainees connect their lack of confidence in their subject matter knowledge for an outside specialism topic to their ability to develop their own ideas for lessons. "Sticking to the scheme" enabled them to feel safe and secure.

Another approach to teaching outside specialism was expressed by George, a "working-confident" physicist:-

> "I think I just don't do enough for biology…you're always looking at your notes checking you've spelt [words] right, whereas in physics you can go off at a tangent because you know you haven't got a problem explaining something…" (George, physicist)

In contrast, Simon, a "super-confident", expressed confidence in his ability to teach outside specialism:-

> "…as long as I'd prepared I felt confident teaching the subject, I was quite comfortable, if you said I was teaching physics top set [most able children], I would go away… do my research and then I'd be pretty comfortable, you might always get a question where someone might pull you up, but then you just say to them I'll have to go and look at that." (Simon, chemist)

Thus, trainees perceived differences in confidence for within and outside specialism teaching, and articulated reasons for these that corresponded with their questionnaire responses.

Views about teaching within specialism

Eight interviewees thought that learning objectives were achieved more easily when teaching outside specialism. This is counter-intuitive to expectations, supporting questionnaire data reported above (p 10). Three trainees said that initially they knew "too much" and failed to select information effectively. Mary, for example, found a much lower knowledge level than expected was required:-

> "…at the start, [with my KS4 biology class] I didn't think [the learning objectives] were all met. They were a "Gifted and Talented" [high ability] class….I was going quite quickly … and I really enjoyed it. I don't think they were keeping up with me as well as I thought they would do….Towards the end things were better and I would say yes, the learning objectives were being met. In chemistry I would say yes, they were met, because I was sticking so closely to the Scheme [of Work]" (Mary, biologist)

Matthew commented:-

> "I feel that teaching outside specialism is better because to a certain extent I 'm learning as the children are, so I can see [the topic] from their angle, and there is no confusion about what they need to know… With physics it's different … there were times that I knew I was thinking [about] quite high level stuff and then dumbing it down to something they would understand, and that sometimes made my job a bit harder …[I didn't have] enough experience teaching low level things" (Matthew, physicist)

The feeling of having to condense specialist subject matter knowledge was expressed by John, whose comment contributes to this paper's title:-

> "[In chemistry and physics lessons] I could explain things at the level [they] should be explained at. For a biology concept you've got all this [knowledge] in your mind overriding what you're telling them. [You know what you say is] almost a white lie, it should be in much more depth, or there are things that you know need to be accompanied with it [that are] not part of the curriculum, its not part of what they need to know. There is a conflict in your head" (John, biologist)

None of the interviewees whose early teaching was more successful outside specialism connected variation in success explicitly to strategies for preparation, although three noted differences in their strategies. John, for example, relied on his prior learning in school as preparation for within specialism teaching, whereas he more actively prepared for physics and chemistry lessons:-

> I: How did you prepare the subject knowledge you needed?
>
> J: For biology I already had an idea of what I'd already done in school myself… I did think about what I'd learned and I did find it easier to remember the biology related lessons … so planning biology lessons, I think I'd already thought about it before coming on the course…
>
> With regard to chemistry and physics …there was a lot more preparation, relearning things …[for example] I haven't touched on any physics … since GCSE. …[so] there was a lot more preparation, I used colleagues in school, speaking to other physics teachers, and other people on the course, getting their advice…
>
> I: So when you were preparing you were more aware of spending time on outside specialism?
>
> J: Yes definitely… I took the [school] textbook … home and look[ed] at that, but I tried to go above that, because children have questions, they want extra bits of information… If you only understand [a topic] to the level they need to learn it, you're never going to be able to teach it, so you need to learn it a couple of steps ahead so you can deal with those unexpected questions and understand it further than is expected for them"

In contrast, Simon, who reported no differences in lesson success, consciously used the same strategies to prepare lessons in both domains, explaining that achieving outcomes depended on finding good activities:-

> "…In terms of the learning objectives they were all roughly similar… in terms of activities I would go out of my way to look in biology to find something a little bit better [than the school's Scheme of Work] so I'd go on the internet and find interactive games. In classification, I did find a few, so some of my lessons were better than in chemistry…. it just came down to the activities." (Simon, chemist)

Simon makes explicit that selection of appropriate instructional strategies is one factor that aids successful lessons. Trainees relying on prior knowledge alone experienced more difficulty in achieving successful lessons within specialism in the early stages of their teaching.

The need to select appropriate instructional strategies and over-reliance on inappropriate ones is illustrated by Jane, a chemist, who copied the style of chemistry teaching she experienced at school:-

> ”A lot of the chemistry I learned at school was just copying off the board… you try hard to avoid this, but there’s parts where it comes back that that’s what you do..” (Jane, chemist)

Jane’s school experiences exerted a powerful influence on her intuitive approach to teaching chemistry; as she had found the subject relatively straight-forward, her instincts led her to want to teach as she herself was taught, on the assumption that the learning outcomes would be the same:-

> “…you’ve had all that background knowledge and spent all that time learning it … you can’t then understand why other people don’t get it…” (Jane, chemist)

Jane realized she could not make these assumptions, and subsequently changed her practice.

Finally, Val, a biologist, illustrates that some trainees are closed to the impact of their teaching on children, until faced with difficult information:-

> ”..with respiration I thought I had gone through the topic really thoroughly… a lot of them didn’t do well in the end of topic test.. Being a biologist didn’t seem to work..” (Val, biologist)

Val is expressing her realization that possession of good SMK on her part is not the only factor determining learning outcomes.

A “continuum” of experience from Simon, through John and Jane to Val can be seen here. Simon grasped early on the need to transform his SMK into activities, using the same strategies for preparation both within and outside specialism. John and Jane relied on prior experiences to help them survive, rather than transforming SMK. Both realized the flaws with this approach. Finally, Val taught first, then reflected from the students’ test results on her performance. Interestingly, Simon and Val both fell into the “super-confident” category (see p 11) – in Val’s case this proved to be over-confidence. These data suggest the importance of aiding trainees to develop reflective practices early on.

Handling subject knowledge-related questions

Trainees’ initial apprehension at being asked questions they could not answer was apparent. For example, Jane, a highly qualified trainee with a doctorate degree, was one of the fifteen most anxious, according to her questionnaire responses (see p 12):-

> “At the beginning one of your biggest fears is that they are going to ask you things that you don’t know and you are thinking, ‘What am I going to say?’ … but as you get into the job you realize …you don’t have to know everything and they won’t really ask you the questions you’re thinking because [the students are] not that

advanced …– its like a fear of the unknown. They don't ask you things that you think they're going to." (Jane, chemist)

Other trainees noted their strategies for handling questions were better in their specialist subjects. Mark who expressed confidence in his ability to handle questions, said:-

> "…the only thing with physics was that I needed to know what they needed to know, but if there was something outside that, then bringing it into the lesson wasn't a problem, and if there was something where I was asked a question and I wasn't sure about it I made a point of telling them I would find it out." (Mark, physicist)

John, a "working confident", learned his material "a couple of steps ahead" of the children so that he could handle questions. He was asked if he was conscious of being able to handle questions better in biology than physics and chemistry:-

> "In a way, but I was never scared of children asking questions, if I didn't know the answer I would say so, at first, I thought it would be the end of the world, how stupid would I look … but yes, if a child asked me a biology question I would be much more confident answering it than in physics or chemistry, but if someone asked me a question in physics and I didn't know I would find out and answer it the next lesson."

Thus, the ability to handle questions seems to rely mainly on trainees' self-confidence. Trainees take a pragmatic approach, finding effective strategies for handling questions to which they don't know the answer and that children are less demanding than they expected.

Changes in SMK sources and preparation during the PGCE course

Ten interviewees stated their preparation time had reduced significantly during the PGCE year. Andrew, for example, said that recalling SMK became easier as training progressed:-

> "My subject knowledge in science has been sleeping. And its all come out again, in this year…[now] subject knowledge takes a back seat to creativity" (Andrew, biologist)

His use of the word "creativity" suggests he has moved from "survival" and transmission of knowledge to "transformation" of SMK.

The notion of "speeding up" may reflect trainees' increasing confidence in handling classroom situations, reducing the time needed to get their SMK to a level they felt brought confidence.

Harriet was one trainee who used unchanged approaches throughout the course:-

> "In the diagnostic [first, short teaching placement], I taught only KS3, and again I read the textbook, the knowledge required was so much simpler…. I don't think my strategies did change, I was reading and talking to teachers,

> sometimes I used the internet…. So I don't think they did change." (Harriet, biologist)

Again, pragmatism plays a role -trainees know what is expected of them and devise coping strategies. They become more skilled at applying these as the course continues.

Discussion

Trainee science teachers' SMK sources for within and outside specialism teaching

Evidence (Tables 2 and 3) indicates that these science trainees use more SMK sources for preparing lessons outside specialism than within specialism. Trainees rely on experienced colleagues and school materials more frequently when preparing outside specialism lessons. Trainees also practice unfamiliar experiments before lessons and consult technicians more often for lessons in this domain. The questionnaire and interview data together suggest that intense SMK preparation helps transformation to PCK, as trainees believed their efforts enhanced their ability to deliver outside specialism lessons with appropriate activities that met learning objectives for their students, as well as giving confidence in their teaching skills.

SMK preparation for within specialism teaching was more casual. Trainees relied on finding out students' knowledge levels. Three trainees used no SMK preparation strategies at all, relying only on prior knowledge. Fewer experiments were tested in advance of within specialism lessons. Perhaps most significant is that trainees consulted experienced teaching colleagues for within specialism preparation much less frequently. In terms of achieving learning objectives, eight interviewees indicated their within specialism lessons were in some respects poorer than outside specialism lessons. Although none explicitly connected this to poor preparation, a link between the paucity of SMK sources used and achievement of learning outcomes seems distinctly possible.

Three interviewees indicated that their difficulties teaching within specialism arose from an inability to select appropriate information from their knowledge base, allied to a lack of experience at teaching "low level" material. The description as a "conflict" is powerful – awareness of a wide range of interlinking concepts and partial truths may hinder selection of the best approach to take or strategy to use. This may be a contributing factor to trainees' inability to transform within specialism SMK to PCK. A lack of SMK for outside specialism teaching seems to lead automatically to more successful transformation to PCK, most likely because trainees involve experienced colleagues and are academically able enough to take in new (or revise old) information rapidly. For teaching within specialism, interviews revealed that trainees work out what to do for themselves over different time periods.

Of course, these comments do not apply to all trainees: there is evidence that 20 – 30% of the cohort were equally successful at teaching in both domains. Interview data suggest these trainees are those who perceived at the earliest possible stage that successful teaching depends (at least to some extent) on good, appropriate activities – that is, somehow, they hit on the importance of transforming SMK to PCK very early in their practice. Their own personal SMK appeared secondary to ensuring that appropriate activities were found and prepared in a suitable format for teaching.

A second finding is the contrast in importance that trainees place on SMK sources from teaching practice schools and HEI-based sessions. Despite attending sessions that, at the time, were rated (verbally and anecdotally) positively, few trainees used any HEI-based materials or ideas regularly, using almost entirely SMK sources from their teaching practice schools. We can only speculate as to possible reasons: for example, HEI sessions may be too generic to be useful to specific school situations, despite efforts to make them relevant; trainees may feel forced to abide by schools' strict Schemes of Work; the time lag between an HEI session and teaching a topic may be too long, so the session is forgotten; or sessions were simply too radical and contrasting to what really goes on in school. Science education research is probably perceived as too esoteric and difficult to access, as well as being difficult to use directly (one trainee commented to this effect in her questionnaire). Misconceptions may be already embedded in schools' Schemes of Work, or are no longer fashionable in the movement in England and Wales towards general scientific literacy.

Trainee science teachers' confidence for within and outside specialism teaching
A mixed picture is observed in data relating to trainee science teachers' confidence. About 20% of trainees showed no difference in confidence levels for teaching in either domain. This "super-confident" sub-group seemed to have prepared themselves mentally for the task of teaching all aspects of science. This group aside, it is probably fair to say that most trainees inevitably showed some anxiety for outside specialism teaching, at least in the early stages of their teaching practice experiences. A sub-group of about twelve demonstrate particularly "anxious" qualities. They feel nervous about deviating from prescribed Schemes of Work and express concern about answering subject-related questions. However, observations made outside the confines of this study indicated that a majority of these trainees developed good coping strategies and worked hard to overcome both their nerves and any initial apprehension.

The trainees in this study are aware that they are well-qualified academically. Over-confidence for within specialism teaching among some is therefore to be expected, at least in the early stages. Trainees vary in their ability to recognise this - interview data point to a possible continuum in the extent to which trainees can reflect meaningfully on their practice.

Trainees' strong academic backgrounds probably also contributed to their SMK development for outside specialism teaching. Around half express preference for teaching their specialism, but also imply they are content to learn new material. The confidence statement responses show that about one-third feel less confident teaching outside specialism, but also don't mind doing this. Evidence indicates that trainees know how to develop their SMK, and are resourceful and resilient in using a range of sources. The average age of 27 suggests that a good proportion of trainees come into teaching from previous jobs, bringing skills that confer maturity in handling novel situations.

The "super-confident" trainees are older than average and particularly well-qualified. Age and work experience may contribute additional maturity at handling unfamiliar situations, greater flexibility in thinking and the ability to take in and act on new knowledge under pressure. Parents of school-aged children familiar with school environments and used to juggling a variety of situations simultaneously tend to fall into this category.

Conclusions, limitations and practical relevance

Conclusions

These data, albeit of a preliminary nature, add to evidence that SMK clearly exerts an influence on teachers' practices. This study, set in a training environment, supports Davis's (2003) findings, indicating that good SMK helps trainee teachers select appropriate instructional strategies. However, we may need to adjust our definition of "good", as these data suggest that 75% of interviewed trainees, who possessed "good" SMK from their degree backgrounds, did not teach successful within specialism lessons, at least in the early stages of their teaching practices. Counter-intuitively, transforming SMK and, hence, selection of appropriate instructional strategies, seemed to occur more consistently when teaching outside specialism topics. This position may change as trainees become more experienced. Hashweh's (1987) findings, for example, contradict these data. Appleton and Kindt's (1999) work, also with experienced teachers, supports the connection made here: when teaching outside specialism trainees express a lack of confidence in their SMK and work hard to remedy this. However, the role of colleagues is clearly different – Appleton and Kindt show collegial support is valued among teachers post-training, whereas this study shows trainees only ask for this when preparing for outside specialism teaching. Youens and McCarthy's (2007) work suggests that trainees may think seeking colleagues help for outside specialism teaching is regarded as "safe", while asking for help for within specialism teaching, that is, for a topic they are supposed to "know", may signal weakness.

The effectiveness of specialised, collegial support on outside specialism teaching supports the findings of Luft et al (2003) and Hoy and Spero (2005). These data also confirm the work of Youens and McCarthy (2007) in showing that school-based materials are used much more frequently than HEI-based sources for developing SMK (discussed below). Teacher educators and school mentors should strongly encourage trainees to seek (or insist that they take) advice from experienced colleagues for teaching in both domains, as well as consider the role that HEI-based sessions could play.

These data do not provide clear support for de Jong (2000) and van Driel et al (2002) in asserting that good SMK helps trainees be more aware of students' difficulties, although, of course, these studies presented other factors as also being involved. In this case, trainees became aware of students' difficulties when learning SMK themselves for outside specialism lessons. No awareness of difficulties was encountered for within specialism lessons – rather, trainees tended to over-estimate students' abilities, at least initially.

The value placed on HEI-based SMK sessions is questioned. Much time is invested in making these as valuable as possible by including latest research findings, information about up-to-date issues in science education and practical experiments, as well as using experienced teacher colleagues and up-to-date published school materials to help make sessions relevant to practice. Nevertheless, trainees make little use of these sessions as an SMK source, focusing instead on materials available in school. A second outcome is the need to ensure mentors are aware of the content and potential value of HEI-based sessions, and for teacher educators to be yet more explicit as to how to utilise HEI materials, misconceptions and research in lesson preparation.

Limitations

Naturally, the study is limited – firstly by the fact that data are collected from one institution and at present constitute a relatively small set. Timing of data collection may mean that trainees' views have changed during the year - data were collected late in the PGCE course. Different views may have been expressed earlier, although interview and questionnaire data together collected over a three month period, suggest that responses are reliable. The questionnaire was designed for this study and has not been validated through use elsewhere, other than by discussion. However, responses from the two cohorts showed no significant differences, and interviewees responded in very similar ways over the two years of the study to date. Further, the interviews did support the questionnaire data – trainees were invited to talk openly about their experiences, without direct reference to the questionnaire, and did so in ways that supported the viewpoints they expressed in their questionnaire responses. This suggests that questionnaire responses were internally reliable.

An additional limitation is that what we read is trainees' viewpoints – they were self-reflecting. No information was gained from other sources, such as mentors or tutors to support these observations, so the statements about "success" or "failure" of specific lessons are entirely based on the trainees' perceptions. Hence, of course, findings must be regarded as tentative.

Practical relevance

Despite the limitations, the information gathered illuminates the issue of SMK for science teacher development in a training setting in a novel way. Trainees' efforts to remediate weak SMK, including consulting experienced colleagues for advice, leads to outside specialism lessons being successful in the early stages of teacher development. Possession of "good" SMK as prior knowledge is insufficient to enable all trainees to prepare and deliver successful lessons within specialism, as they lack experience to transform SMK to PCK effectively. Further, the role of good support in aiding teacher development is confirmed.

The issue of how best to prepare trainees for teaching remains open. This study draws attention to the possibility of identifying sub-groups of trainees with different characteristics. Further work may help identify "super-confident", "working confident" and "anxious" groups more rigorously, with a view to offering different specialised support. Differentiation of support may help enhance the skills of the "super-confident", and encourage more trainees to develop these characteristics.

The connection between "super-confident" and the ability to transform SMK to PCK was apparent. Trainees with these characteristics challenge the assumption that science specialist subjects are best taught by those possessing specialist degrees. High academic performance in a specialist subject is not an automatic precursor to good teaching. Trainees with good academic backgrounds tend more often to work from the "survival" perspective and regard teaching as knowledge "transmission". Interviews in this study show the limitations of this approach. We anticipate that most trainees make the transition from "survival" and simple transmission of knowledge to transformation of SMK at some stage during the training programme. The role of colleagues in providing support is identified as a factor aiding success: where help is asked for, evidence presented here shows this was always regarded positively.

In terms of the specialist – generalist debate, this paper indicates that the “subject specialists are best” assumption (Introduction) is not proven. Evidence here is more supportive of the notion that possession of genuine “teacher skills”, that is, the ability to transform SMK to PCK, is a more significant factor influencing success as a trainee science teacher than simply possession of a good degree in a specific subject. The trainee whose comment inspires this paper’s title is an academic biologist talking about teaching biology. His conflict was not about how he should teach physics. Of course, following trainees’ development long term may yield changes – over time, perceptions of confidence and abilities may change with experience, suggesting that a longitudinal study is worthwhile.

This study points towards the unique, raw nature of teachers’ starting positions. In the early stages, heavy reliance on teaching practice schools is perhaps not unexpected, given the wide range of intense experiences that these naive beginners face. Research with experienced teachers post-training shows that skill development continues. A greater reliance on HEI-based sources may occur when the basic range of teaching abilities are in place. Accordingly, we may need to review the nature and content of HEI-sessions on teacher education courses to ensure maximum impact during training. However, over the early years of a teacher’s career, full support from HEI- and school-based colleagues is effective in aiding their development. Overall, then, the practical relevance of this study lies in the notion that assessing trainees’ personal characteristics and offering appropriate, realistic, professional support from both HEIs and schools in accordance with these may help science teachers develop in the best possible ways.

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Subject specialism	Biology		Chemistry		Physics		Totals	
No. of trainees	39 *(55)*		24 *(34)*		8 *(11)*		71 (*100%)*	
Gender	Male	Female	Male	Female	Male	Female	Male	Female
	12	27	10	14	6	2	28 *(39)*	43 *(61)*
Age								
21-25	8	21	3	4	4	1	41 *(58)*	
26-30	2	2	4	5	1	0	14 *(20)*	
31-35	1	2	2	3	0	0	8 *(11)*	
36+	1	2	1	2	1	1	8 *(11)*	
Degree class								
1st	3	2	1	4	2	0	12 *(17)*	
2:1	5	14	1	4	2	0	26 *(37)*	
2:2	3	8	4	4	1	1	21 *(29)*	
3rd	0	0	2	0	0	0	2 *(3)*	
Not stated /other	1	3	2	2	1	1	10 *(14)*	
Higher degrees	5	4	4	6	0	1	20 *(28)*	

(Figures in parentheses are percentages throughout)

Table 1: Science trainees' backgrounds: gender, age and degree classification against subject specialism

	Ranked 1 or 2	3 or 4	5 or 6	7 or 8	9 or 10	Total
Making notes	29 (41%)	13 (18)	7	6	6	61
School colleagues	24 (34)	19 (27)	13 (18)	3	2	61
Other trainees	9 (14)	20 (27)	14 (20)	9	9	61
Internet	16 (23)	23 (32)	10 (14)	9	3	61
Science Education Research	1	1	5	15 (21)	39 (55)	61
Misconceptions Materials	1	6	14 (20)	18 (25)	22 (31)	61
Textbooks	30 (42)	16 (23)	9	5	1	61
Exam papers, etc	4	12 (17)	18 (25)	16 (23)	11	61
HEI sessions	5	7	20 (17)	23 (32)	6	61
University notes	3	5	13 (18)	17	23 (32)	61

Figures in parentheses are percentages

Table 2: Science trainees' ranking of ten subject matter knowledge sources from a pre-prepared list

SMK source	Within specialism teaching	Outside specialism teaching
School colleague or other trainee teacher	7	33
Textbooks, school resource packs, teacher materials	19	38
Internet	19	18
Formal documentation such as Exam papers, National Curriculum document, School Schemes of Work	10	12
Prior knowledge from University degree or job	14	0
Information from an HEI-based session	2	2
Other source, e.g. revision guide, safety guide, practising experiments, prior knowledge check, note-making	8	15
Misconceptions information	4	5
Trainees stating “no sources used”	3	0

Table 3: Summary of trainee science teachers’ subject matter knowledge sources for within and outside specialism teaching

Statement Pair	Likert scale response Statement	Strongly agree	Slightly agree	Neutral	Slightly disagree	Disagree /strongly disagree	NR	Total
Preference	I prefer to teach topics in my specialism	22 (31%)	18 (25)	15 (21)	5	11	0	71
	I am pleased to teach topics in all areas of science	41 (58)	18 (25)	9	3	0	0	71
Confidence	I don't need to teach my specialism to feel confident	34 (48)	13 (18)	15 (21)	1	7	1	71
	I am less confident teaching outside my specialism	15 (21)	23 (32)	16 (23)	12 (17)	5	0	71
Questions	I am nervous of being asked a question I can't answer	17 (24)	15 (21)	9	14 (20)	16 (23)	0	71
	I can handle difficult questions in non-specialist areas	25 (35)	25 (35)	13 (18)	14 (20)	4	0	71
SMK attitudes	I find it difficult to develop my subject knowledge outside my specialist area	2	3	10	15 (21)	41 (58)	0	71
	I enjoy learning new subject knowledge outside my specialist area	46 (65)	13 (18)	11	1	0	0	71

NR = No response

Table 4: Trainees' responses to Likert scale statements about preferences, confidence, handling questions and attitudes towards learning new SMK

Appendix 1: Questionnaire

Developing trainee science teachers' subject knowledge

Background information

Name ________________________________ Gender ________ Age __________

1st degree subject and class ________________________

Higher degrees ____________________ Subject specialism on PGCE ________

1. Please complete the table showing science topics you have taught so far.

In your specialist area	Key stage	In areas outside your specialism	Key stage
[Space provided for lists]			

2. From the specialist list, choose one topic you found especially "easy" to teach (i.e. you felt confident you could teach it well). Describe what you did to prepare the subject knowledge required.

3. From the non-specialist list, choose the topic you found hardest to teach (i.e. you felt the most unconfident you could teach it well). Describe what you did to prepare the subject knowledge required.

4. Here is a list of strategies that trainee science teachers may use for developing subject knowledge. Rank the items in order from **1(Highest) – 10 (lowest)** according to how useful you think these are. *Please number each item separately; don't rank two with the same number.*

Strategy	**Ranking from 1-10**
Making notes from textbooks	
Asking colleagues at school	
Asking other trainees	
Searching the internet	
Reading science education research	
Reading misconceptions literature	
Reading textbooks	
Trying exam papers / questions	
Using information from University sessions	
Using university notes from your degree course	

5. Here are some statements about subject knowledge and teacher confidence. Select the alternative in each case that corresponds most closely to your opinion as it stands based on your teaching experience so far.

	1- strongly agree				5 strongly disagree
I prefer to teach topics in my specialist area. P	1	2	3	4	5
I enjoy learning new subject knowledge outside my specialist area. A	1	2	3	4	5
I am nervous that I will be asked a question I cannot answer. H	1	2	3	4	5
I am less confident when I teach outside my specialist area. C	1	2	3	4	5
I can handle the situation if I am asked difficult questions outside my specialist area. H	1	2	3	4	5
I am pleased to teach topics in all areas of science. P	1	2	3	4	5
I find it difficult to develop my subject knowledge outside my specialist area. A	1	2	3	4	5
I do not need to teach my specialism to feel confident as a teacher. C	1	2	3	4	5

Please indicate here if you would be prepared to take part in a (short) recorded discussion about the issues being explored in this study. o

Thank you very much indeed for your help.

Appendix 2: Interview questions

1. Please confirm the topics you taught at KS3 and KS4 on both your teaching practices.

2. How did you prepare the subject knowledge you needed for teaching?

3. Did you use the same strategies for preparing subject knowledge for teaching topics within and outside specialism? Please explain.

4. Were you aware of differences in learning outcomes for the children when you taught within and outside specialism topics? Please explain

5. How did the quality of your lesson preparation affect the achievement of learning objectives?

6. Have your strategies for preparation changed during the PGCE course? Please explain.

Trainees were also asked to bring lesson plans, teaching materials and evaluations of their teaching for within and outside specialism lessons that they felt best represented their work. Discussion about these followed the interview questions.