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Acquisition of Science Subject Knowledge and Pedagogy in Initial Teacher Training

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Acquisition of Science Subject Knowledge and Pedagogy in Initial Teacher Training

Report to the Wellcome Trust

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Contents

Executive summary

There is concern about how trainee science teachers acquire subject knowledge and pedagogy to teach across the sciences in secondary schools. This report addresses the question: How do one-year postgraduate Initial Teacher Training (ITT) courses in England and Wales support trainees' acquisition of subject knowledge and topic specific pedagogy across the sciences?

This study is the first that has attempted to investigate the acquisition of subject knowledge and topic specific pedagogy by trainee science teachers in secondary ITT courses and has benefited from comprehensive support by science ITT tutors in England and Wales.

The findings are presented in four sections:

- The qualifications of trainees and Higher Education Institution (HEI) course intentions (Section A);
- The extent to which subject knowledge and topic-specific pedagogy are addressed on one-year science ITT courses (Section B);
- The ways in which trainees acquire and use subject knowledge and topic specific pedagogy (Section C);
- The extent to which the subject specific course elements meet trainees' perceived needs for the Newly Qualified Teacher (NQT) year (Section D).

A. Qualifications and course intentions

- Most HEI tutors said their trainees were being prepared to teach across the sciences to Key Stage (KS) 4 (age 16 – GCSE equivalent).
- There is an imbalance of specialists on ITT courses, with the number of biologists far exceeding chemists and physicists (approx 5:3:2).
- The minimum degree requirement HEI tutors accept for a trainee biological science teacher is higher than for a trainee physical science teacher.

- Nearly one-third of trainees who regard themselves as physics specialists have a degree with limited identified physics content.

B. Addressing subject knowledge (SK) and topic specific pedagogy (TSP)

- The HEI is the main location for formal engagement with subject knowledge and topic specific pedagogy.
- HEIs provide formal sessions that are a mix of subject knowledge and topic specific pedagogy with greater emphasis placed on topic specific pedagogy.
- Subject knowledge and topic specific pedagogy sessions in HEIs are mainly workshops led by tutors, most of whom stated they were actively engaged in science education research.
- The amount of teaching time allocated to science appears to be very variable between HEIs.
- How Science Works (practical and enquiry skills, critical understanding of evidence, applications and implications of science and communication), taught in separate sessions, does not appear to be a major identifiable focus in the HEI-based parts of courses.
- HEI tutors expect school mentors to monitor and set targets for subject knowledge and topic specific pedagogy.
- A minority of HEI tutors expect subject knowledge and topic specific pedagogy to be routinely addressed in formal mentor meetings.

C. Trainees' acquisition and use of subject knowledge and topic specific pedagogy

- Subject knowledge enhancement (SKE) courses led by ITT staff are perceived by trainees as more useful than those led by academics in science departments.
- Trainees view the subject knowledge audit process as inefficient and ineffective.

- Most trainees identify the best time for developing subject knowledge as the point at which they are required to teach it.
- Trainees mainly use material resources to develop their subject knowledge whereas they use human resources to develop topic specific pedagogy.
- Trainees rate peers high in the rank order of resources used to access both subject knowledge and pedagogy.
- The classroom teacher is an important resource for subject knowledge and topic specific pedagogy development.
- HEI sessions rank highly as a resource for developing topic specific pedagogy.

D. Trainees and the Newly Qualified Teacher (NQT) year

- For Science NQTs, physics topics were a high priority for continued professional development (CPD) courses in the first year of teaching.
- Trainees identify behaviour management and assessment as priorities for CPD courses in their NQT year.
- Processes to address subject knowledge and topic specific pedagogy are considered by trainees and HEI tutors to be transferable to unfamiliar topics.

ITT courses provide a sound basis for developing subject knowledge and topic specific pedagogy in key topics. However, it is unrealistic to expect trainees to develop secure subject knowledge and topic specific pedagogy in all topics in their specialist and non-specialist areas at Key Stages 3 and 4 (11–16 years) during a one-year ITT course.

Introduction

Trainees entering a one-year Initial Teacher Training (ITT) course in secondary science in England and Wales usually have a first degree in some aspect of either the biological or physical sciences. Some undergraduate science degree courses take a ‘pick and mix’ approach leading to graduates with experience of a range of sciences, but with relatively limited in-depth knowledge of physics, chemistry or biology. Few trainee teachers will have studied all three science subjects to A-level (Institute of Physics, 2002). Many may have only studied one science to A-level and for these trainees their study of other sciences will have been limited to GCSE. Although the Training and Development Agency (TDA, 2010) requirement is that trainees are prepared to teach across the sciences to Key Stage 3 and in their specialism at GCSE onwards, studies by Lock and Soares (2005), Lock, Soares and Foster (2009) and the House of Commons Children, Schools and Families Committee (2010) report that schools require many NQTs to be competent to teach all sciences to GCSE level. This places a considerable demand on trainees developing their subject knowledge and ways of transforming this knowledge into effective teaching during a one-year ITT course. Even in teaching their subject specialism, trainee teachers need pedagogical content knowledge to transform good subject matter knowledge into effective lessons (Van Driel, De Jong and Verloop, 2002; Kind, 2009).

DfES (2006) proposed that staff qualified in the subjects they are teaching are likely to generate more Science, Technology, Engineering and Mathematics (STEM) qualified learners and since the number of physical science graduates entering teaching is low this may be a cause for concern. The Report of the Science and Learning Expert Group (Department for Business Innovation and Skills, 2010) stresses the importance of providing subject specific training in ITT, specifically recommending that there should be further investigation into:

> *‘..the consistency between initial teacher training* [ITT] *providers in the balance between subject-specific and general pedagogical training to*

ensure that subject specific pedagogical training receives a high priority.' (Recommendation 4, p 10)

Our research is therefore timely in that as well as addressing this recommendation it also comes at a time when there is an increased demand for recruiting specialist teachers of physics and chemistry.

In this report the terms '*physicist', 'chemist'* and *'biologist*' are used in line with the NFER (2006) definition of a specialist. The NFER defines a subject specialist as one who has university qualifications in the subject at degree level or above or undertakes training in the subject during their ITT year. For example, a physics specialist (physicist) may have a physics degree or be a graduate of an unrelated subject enrolled on an ITT course specialising in physics.

This study distinguishes between formal (timetabled) and informal provision of SK and TSP support in ITT secondary science courses. The term 'informal' is applied to all contexts that are not part of trainees' timetabled entitlement in HEI and school-based components of the course, matching Eraut's 'non-formal' support (Eraut, 2000).

To summarise, this study focuses on the following question: How do one-year postgraduate Initial Teacher Training (ITT) courses in England and Wales support trainees' acquisition of subject knowledge and topic specific pedagogy across the sciences?

The working documents from which this report was compiled and the research instruments are available at www.rogerlock.com and on the University of Birmingham, School of Education website at www.education.bham.ac.uk/research/project1/SKaPITT.shtml.

Research context

The Royal Society (2007) views teachers' science subject knowledge as one of the critical indicators of the quality of teaching. Grossman, Wilson and Shulman (1989, p 27) suggest that there are four dimensions of subject knowledge, or what they term 'subject matter knowledge', that affect the teaching and learning of prospective teachers: content knowledge (factual information); substantive knowledge (explanatory frameworks); syntactic knowledge (how new knowledge evolves); and beliefs about the subject matter. Other studies (Shallcross, Spink, Stephenson and Warwick, 2002) interpret science subject knowledge in terms of Schwab's (1978) definition of substantive knowledge (the facts, theories and disciplines of science) and syntactic knowledge (the procedures of investigating and experimenting) which Roberts, Gott and Glaesser (2010, p 378) also call 'procedural knowledge'.

As trainee secondary science teachers in England and Wales cannot be expected to have studied all aspects of the sciences they will be teaching, their subject knowledge, both substantive and syntactic, will need to be addressed, to varying extents, during their initial teacher education programme.

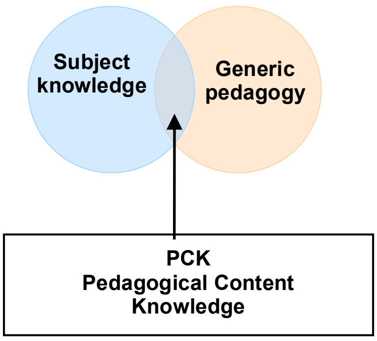
However, developing into an effective teacher requires more than just the substantive and syntactic knowledge of the subject.

> *'…just knowing the content well was really important, just knowing the general pedagogy was really important and yet when you added the two together, you didn't get the teacher.'* (Shulman in an interview reported in Berry, Loughran and van Driel, 2008)

This suggests that a graduate of a particular subject is only likely to start their transformation into a teacher of that subject when they begin to consider how best to teach the subject content in order to make it learnable by others. To account for this, Shulman (1986) introduced the term pedagogical content knowledge (PCK) (Figure 1) and proposed that such considerations included:

'…the most powerful analogies, illustrations, examples, explanations, and demonstrations… the ways of representing and formulating the subject that makes it comprehensible to others.' (Shulman, 1986, p 9)

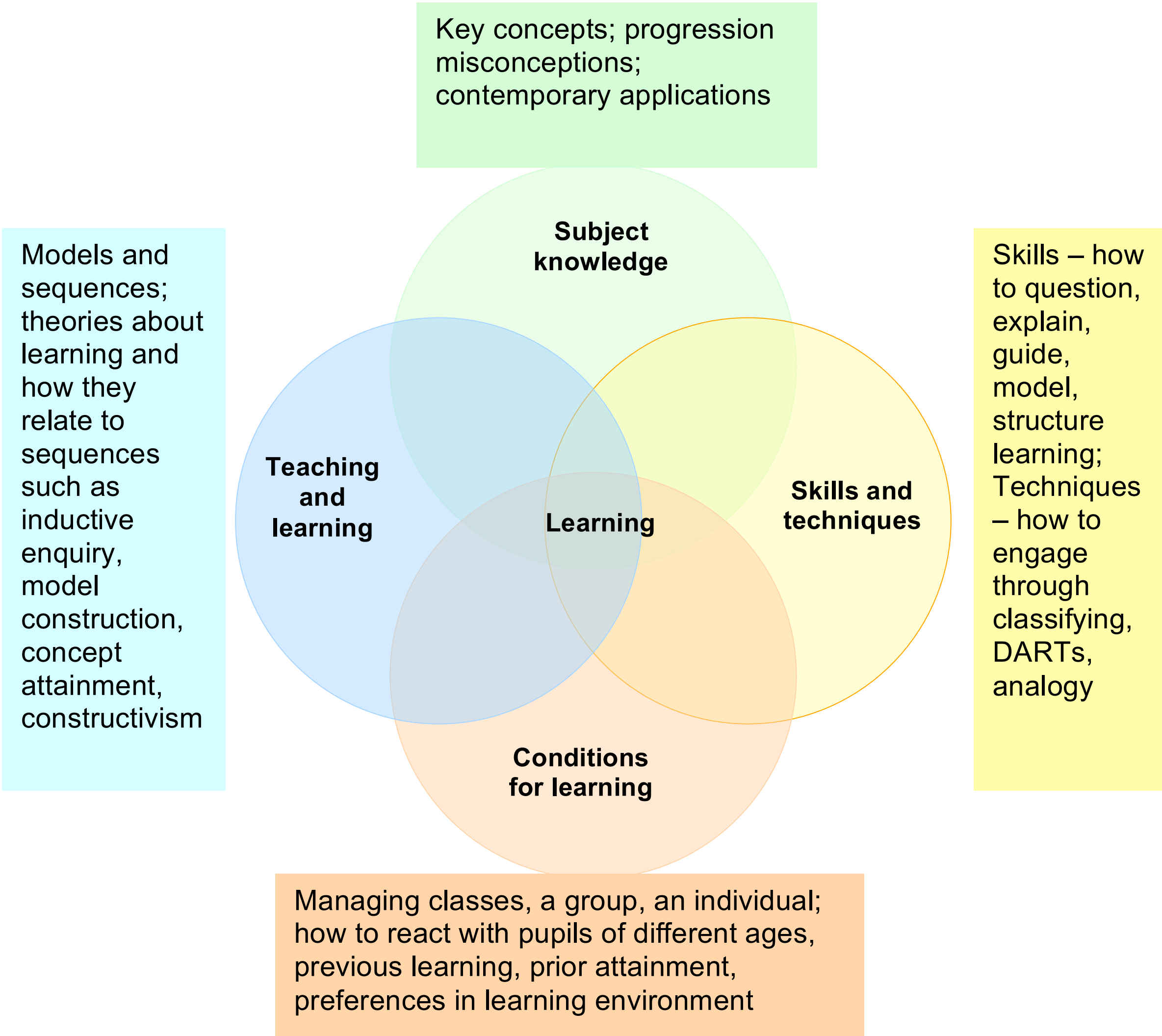
Figure 1. Relationship between subject knowledge, generic pedagogy and PCK



While teacher educators and researchers agree that PCK is a useful construct (e.g. van Driel, Verloop and de Vos, 1998; Loughran, Mulhall and Berry, 2008; Kind, 2009), it is also acknowledged that there are differences in its definition and conceptualisation (Nilsson, 2008). Nevertheless, even though PCK appears to be a common component of the teacher knowledge needed to be an effective teacher of a subject (van Dijk and Kattmann, 2007; Nilsson, 2008), it is not a commonly used term by teachers. This is unsurprising as even guidance provided for teachers through government agencies does not explicitly refer to the term (DCSF, 2008) (Figure 2).

Loughran, Mulhall and Berry (2008) proposed a framework called '*Content Representations'* (CoRes) – key content ideas, known alternative conceptions, known points of confusion, ways of framing ideas to support learning, ways of testing for understanding – and '*Pedagogical and Professional-experience Repertoires'* (PaPeRs) – specific aspects of teaching the topic – to explicitly introduce PCK to beginning teachers. This framework appears to amalgamate the substantive, syntactic and PCK components and introduces a further dimension, specific aspects of teaching a topic.

Figure 2. Talking Science Pedagogy (DCSF, 2008)



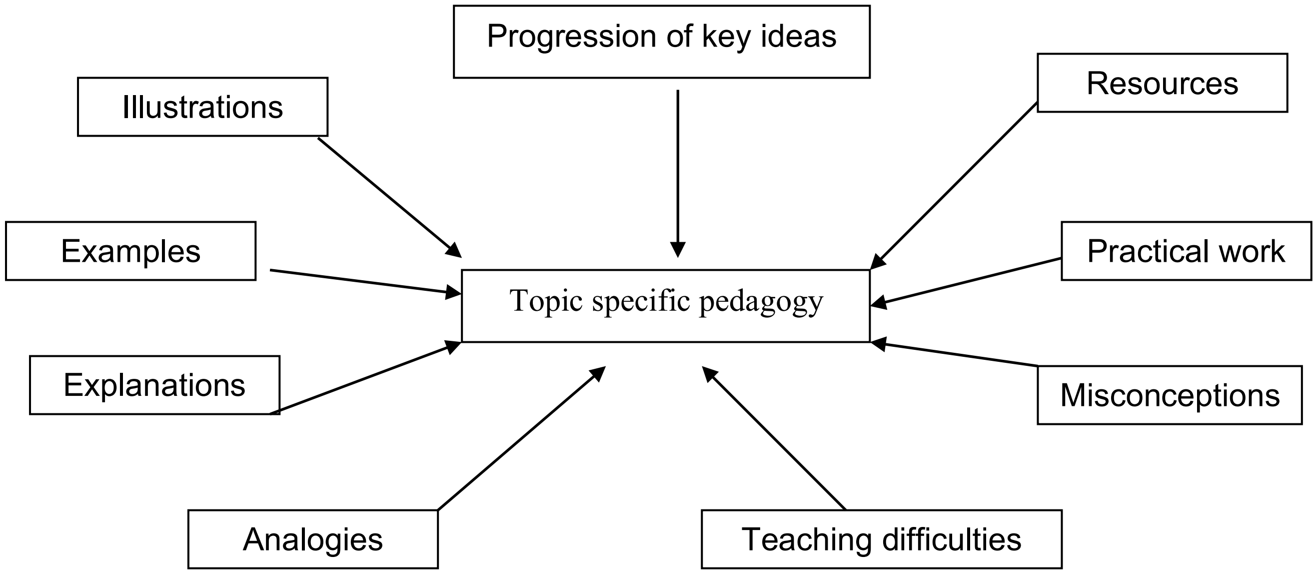
Geddis (1993) proposed that developing teachers need to address pedagogical issues that are content specific:

> *'Beginning teachers need to learn not just "how to teach" but rather "how to teach electricity."'* (p 675)

This suggests that to be an effective teacher of physics it is necessary to not only know the content (subject knowledge) of the various topics (e.g. forces, energy etc), but also '*…the particular teaching and learning demands of that particular topic'* (Bucat, 2004, p 217), the topic specific PCK.

In this report, subject knowledge (SK) is the subject content knowledge related to a particular topic, a term also used by Childs and McNicholl (2007), and topic specific pedagogy (TSP) is the associated specific pedagogy needed to transform the particular content of that topic to make it understandable to learners (Lock, Soares and Foster, 2009). This corresponds to the term subject specific pedagogical knowledge used by Burn, Childs and McNicholl (2007). Figure 3 illustrates our conceptualisation of TSP as ways of re-working the particular topic specific subject knowledge to make it more understandable.

Figure 3. Aspects contributing to topic specific pedagogy



In other words, although the use of illustrations, analogies, misconceptions etc may be applicable to all topics, there are specific and unique pedagogies of these aspects related to each particular topic (e.g. electricity, genetics, chemical bonding), and this we term topic specific pedagogy (TSP).

Methodology

The study employed a mixed methods approach with progressive focusing between the research instruments (document analysis/questionnaires/interviews) and phases in the work (Creswell, 2009). Such an approach was used as it combines the strengths of quantitative and semi-quantitative data derived from large size samples with the richness of interpretive elements derived from more qualitative work with smaller samples. This permits triangulation between methods and allows issues and questions arising from one research instrument to be more closely focused upon as the study progresses. The methods and sample sizes are summarised in Table 1.

Table 1. Research instruments: sample sizes, return rates and data collection periods

Research instrument	Sample size	Responses received	% return	Data collection period
Phase 1				
Document analysis	64	24 HEIs/81 documents	38	Dec 2009 to Jan 2010
Tutor questionnaire	134	72	54	May 2010
Phase 2				
Trainee questionnaire	300	245	82	Jun 2010
Trainee interview	24	22	92	Jul–Aug 2010
Tutor interview	8	8	100	Aug–Sep 2010

Document analysis

All HEIs in England and Wales offering a one-year ITT course in science (including biology, chemistry, physics, geology and psychology) covering KS2–3, KS3–4 and KS3–5) were identified from the Graduate Teacher Training Registry website (GTTR, 2009) (n=64). Science staff were identified from the HEI websites and, where contacts were not clear, by telephoning the HEI. All colleagues on this list (n=160) were emailed in December 2009 informing them of the nature of the research, requesting copies of their documentation relating to university and school-based programmes and assuring them of anonymity. Where no reply was received, a follow up request was made in January 2010. Documents were received from 24 HEIs. In total 81 documents were made available.

The representativeness of this sample was investigated according to a number of parameters (Table 2). Documentation was received from HEIs across England and Wales with no regional bias. Pre and post 1992 universities were both well represented and there were responses from HEIs offering the full range of secondary subject specialisms and key stages (KS). The data in Table 2 suggest that there was no bias with regard to geography, HEI type, KS or specialism.

Table 2. Representativeness of the sample

Criterion	**Description**
Geography	2 East, 8 South and London, 3 South West, 4 North, 5 Midlands, 2 Wales
HEI type	12 of 29 pre 1992 universities (41% return); 12 of 35 post 1992 universities (34% return)
Key Stage	KS2–3, KS3–4, KS3–5
Specialism	Science, biology, chemistry, physics geology and psychology

In developing a usable, valid and reliable method of analysing the documents the following procedure was adopted. Analysis criteria were independently drawn up by the three investigators each using the same, randomly, selected document. The criteria were discussed and conflated to a single agreed list of criteria. These preliminary criteria were used by the three investigators to independently analyse the same documents from two, further, randomly selected, HEIs and the analyses were shared. Any differences that arose were discussed, solutions proposed and agreement reached regarding interpretation. As a result of this process, criteria were refined, definitions of terms clarified and a coding system developed for further analyses. The revised criteria (Figure 4) were used to independently analyse documents from a further HEI to determine inter-rater reliability. This showed a reasonable consistency between the investigators.

The criteria, definitions and coding, complete with two contrasting analyses, were shared and discussed with the project advisory group which verified the methodology and suggested minor modifications. The final criteria used to analyse documents (n=81) from all 24 HEIs are shown in Figure 4.

Spreadsheets were constructed to collate the data from each HEI. The spreadsheets consisted of three pages: the first related to the HEI-based phase of the ITT course; the second to school-based training; and the third to any aspect of self-help (individual study and peer support). Each criterion had a column in the spreadsheet and this facilitated easier cross comparison between HEIs.

As Figure 4 shows, common criteria were used to analyse the course content devoted to How Science Works (HSW), biology, chemistry, physics and earth science. Topics were recorded as described in the documents and where these were accompanied by descriptions of the session content, it was possible to identify if subject knowledge and/or topic specific pedagogy were involved. In the same way it was possible to identify the key stage on which the work was focused and how it was covered.

Where documents identified details of the subject knowledge audit these were recorded, as was any focus on the audit of topic specific pedagogy. In some documents course assignments were used in assessing and/or validating subject knowledge and pedagogy and information on these approaches was also recorded.

Comments from the documents were noted in order to provide qualitative evidence complete with page numbers, allowing the researchers to easily revisit the original documents should this be necessary, for example during tutor and trainee interviews. Possible points which required further investigation or clarification were noted in order to progressively focus the research questions through other research instruments. A course synopsis for each HEI was recorded in order to facilitate the development of a typology of courses.

Although the method was felt to be rigorous, limitations with the methodology encountered during the analyses were noted. There were three main limitations:

1. The documents received were not written for the purposes of this research.
2. Documents varied in their completeness.
3. Documents varied in the level of detail provided on different course aspects.

Figure 4. Criteria used for the analyses of HEI documents

Sheet 1 (university-based part of the course)

Course – code (anonymised)

Overall teaching time (hrs)

Science teaching time (hrs)

Separate sections on: How Science Works, biology, chemistry, physics and earth science

Content analysed for:

- Topic
- Subject knowledge and/or pedagogy involved
- Key Stage
- How covered? (lecture, seminar, workshop, peer presentation)
- By whom? (university tutor, mentor/teacher, external speaker)
- Time (hours)
- Stage in course (early [weeks 1 to 10]; middle [weeks 11 to 20]; late [weeks 21+])

Subject knowledge audit

- Subject knowledge/pedagogy audited
- Format
- By whom? (university tutor, mentor, self)
- How often?
- Who with? (university tutor/mentor/other)

Action/follow up/use
Support for action

Assessment
Assignment including SK/TSP
SK/TSP audit

Comments/quotations and page numbers for later reference

Possible points for exploration by questionnaire/interviews

Methodology limitation notes

Course synopsis

An apparent absence of data in a document might not mean that an activity does not take place or a topic is not addressed. Conversely, a course may not be run as it appears to be set out in the documents analysed. For these reasons the document analysis was not primarily used to produce quantitative outcomes but to generate semi-quantitative and qualitative data. The main purpose was to generate questions to explore in more detail (e.g. about the nature of the SK audit and peer support) using other research instruments (questionnaires and interviews).

In addition, the strategy employed is likely to underestimate the extent of the focus on SK and topic specific pedagogy (TSP) because where only generic titles were given for sessions, e.g. 'Questioning' it was unclear what subject matter might have been addressed in that session and how it was addressed.

Questionnaires (tutor and trainee)

A common approach was used for most aspects of the trainee and tutor questionnaire development. Where there were differences in approach, these are reported separately in the relevant section of the research methods.

Broad areas under which questions might be asked were drawn up using the research questions contained in the original research proposal, discussions between the investigators, aspects requiring more detailed exploration arising from the document analysis (and, in the case of the trainee questionnaire, findings from the tutor questionnaire) and consultation with the advisory group. The questionnaires were developed over several versions (six tutor and four trainee versions) before being piloted with advisory board members and research colleagues. Comments were invited on the content, layout and completion time. All suggestions were considered and implemented as appropriate, particularly where points were made consistently or related to clarity and validity.

Trials of the questionnaires were undertaken by ITT tutors from a range of subject disciplines (tutor questionnaire) and ten science NQTs from a 2008–2009 cohort of trainees (trainee questionnaire). Trial findings were used to improve clarity and validity. The number of mandatory questions was reduced in order to encourage respondents to complete the survey in a reasonable time period. The balance of open and closed questions was adjusted in order to match the time taken to complete the questionnaire with the opportunity for more detailed responses. Paired opposites and repeat questions were included to check the consistency of responses.

Responses to open questions and where the option '*other, please give details*' had been used were independently examined by the investigators and treated in two ways. Firstly, where appropriate, responses were discussed and a coding system developed which was then checked for consistency of use by the investigators. This process resulted in the re-allocation of some '*other, please give details*' responses to ensure validity. Secondly, prose comments were selected for potential inclusion as qualitative evidence.

Tutor questionnaires (only)

An electronic questionnaire using the Bristol Online Survey (BOS) (BOS, 2010) was chosen rather than a paper-based format in order to increase the response rate. This had the advantage of a site licence at the investigating institution, online support and internal expertise.

All science tutors within HEIs in England and Wales offering one-year science ITT courses (n=160) were sent questionnaires with a supporting email. A two-week period for completion was provided during which two email reminders were sent. Replies to the email indicated that the sample size was smaller than 160 due to maternity leave, sabbaticals, non-involvement in ITT, leaving post etc. This reduced the working sample to 134.

During the questionnaire window all queries were responded to and solutions provided to local problems; when asked, investigators encouraged individual responses. However, in some HEIs a nominated tutor responded on behalf of all colleagues. A total of 72 responses were received from the working sample of 134 (54 per cent). Enquiries with the software providers (Bristol Online Survey) indicated that 20 to 30 per cent is the expected return rate for a topical survey (BOS, 2010) suggesting that the response rate to this investigation was good.

The questionnaire provided opportunities for respondents to voluntarily identify themselves and their institution as an indication of willingness to be involved in phase two of the research. Colleagues from 33 different HEIs completed this option showing that at least half of HEIs offering one-year ITT courses in the sciences in England and Wales were represented. The identified HEIs contributed from one to four respondents each (median one) and came from a wide geographical range within England and Wales (Table 3), with all regions represented. They represented pre-1992 universities (12), post-1992 universities (21) and reflected the range of secondary course providers: Key Stage 2–3 (8), 3–4 (25) and 3–5 (50). HEI respondents represented a variety of specialisms including science (27), biology (38), chemistry (39) physics (38) and earth science (1). Overall, the researchers felt that the respondents who chose to identify themselves were representative of provision for secondary ITT in England and Wales and this gave support for generalising data collected by the tutor questionnaire to the wider population.

Table 3. Number of identified HEI institutions responding from regions

Region	Number of institutions responding
London	4
Midlands	6
North East	6
North West	4
South East	7
South West	4
Wales	2

Examples of questions designed to check the consistency of response are identified in Table 4. These take the form of paired opposites (examples 1 and 2) and a repeated question (example 3). The data indicate that there is good agreement which demonstrates acceptable levels of internal consistency.

Table 4. Paired opposite questions and repeated question incorporated into q. 27 shown with response (%)

Example	First question	Second question	Theme
1	27a 16%	27o 16%	Adequacy of SK of trainees before commencing ITT courses
2	27b 61%	27l 51%	Value of teaching SK in university-based sessions
3	27e 64%	27p 63%	Transfer of TSP skills to new areas

Case studies

For institutions to be selected for phase two of the research they had to have provided documents for analysis and submitted an identified tutor questionnaire response offering further involvement with the trainee questionnaire, interview and tutor interview. Twelve institutions met these criteria. A typology of courses had been developed from the document analysis and from this there was a spectrum of courses with different amounts of explicit teaching focused on science SK and TSP (high >27hours, low <27 hours HEI-based provision). In addition, the provision of some courses appeared to be different from most others, for example with a strong focus on misconceptions or with the provision of school-based SK and TSP teaching. Of the 12 HEIs, seven offered 'apparent high' and four 'apparent low' explicit provision of SK and TSP teaching, with one in the middle. When this factor was combined with a desire to have case studies that reflected the geographical distribution, institution type, course type and cohort size of HEI institutions, the six institutions shown in Table 5 were selected.

Table 5. HEIs selected for phase two of the study

High/low explicit provision	PCB/ combined	Age range	Pre/ post 1992 HEI	Geographical location	Possible cohort size	HEI code
High (school-based coaching)	PCB	11–18	Pre	Midlands	45	H024
Low	Combined	11–16	Post	South	21	H025
Mid	PCB	11–18	Pre	West	70	H027
High	Combined	11–18	Pre	Midlands	90	H030
High (misconception)	PCB	11–18	Pre	North	51	H032
Low	Combined	11–16	Post	South	23	H036

Trainee questionnaire (only)

A questionnaire containing open and closed questions was developed to address the research questions and to enable triangulation with, and deeper exploration of, data from the document analysis and HEI tutor questionnaire.

A paper-based questionnaire was used in preference to an online survey in order to maximise the return rate with a completion time restricted to 30 minutes.

The questionnaires were dispatched to the course tutors at each case study HEI and completed between 11th and 28th June 2010 mostly in the final week of the ITT course. The response rate across all six HEI case studies (overall, 245/300) ranged from 71 to 100 per cent (Table 6).

Table 6. Trainee questionnaire response rates

	H024	**H025**	**H027**	**H030**	**H032**	**H036**
Response rate (%)	100	71	79	71	88	91

A number of paired opposites and repeated questions were incorporated into the questionnaire to check the consistency of the responses. The data indicate that the responses showed consistency.

Analysis of the data sought to explore patterns in trainees' responses within each of the six institutions and patterns across the six institutions.

Interviews (trainee and tutor)

The questions for the interviews were agreed amongst the investigators based on discussions between themselves and the advisory group and on questions or data derived from tutor and trainee questionnaires, the document analyses and, in the case of the tutor interviews, the trainee interviews.

Trials were carried out with five trainees and three tutors drawn from two HEIs and this resulted in modified protocols. This protocol took the form of a flow diagram containing key interview questions, with space to annotate verbatim comments as necessary. Before the interview, the specific HEI trainee and tutor questionnaire(s), course documents and, in the case of the tutor interviews only, trainee interviews, were consulted for course specific aspects which could be investigated further during the interview.

Interviews were digitally recorded in order to facilitate further listening, reliability analysis and transcription if required. Recordings of the trials were listened to by more than one investigator with subsequent modifications made to protocols as well as checks on the consistency of data recorded in the template.

The interviews lasted approximately 30 and 40 minutes (trainees and tutors respectively). One investigator carried out all the interviews and another listened to two trainee and two tutor interviews. Differences regarding interpretation were discussed and resolved to arrive at a consistent interpretation in order to enhance the reliability of the analysis.

Trainee interviews (only)

Trainees offering interviews from the questionnaires were contacted by email. Those responding to the email were then contacted by telephone to arrange a convenient time for an interview to take place. Four volunteer trainees in five of the six case study HEIs were interviewed. In one HEI two trainees were interviewed owing to fewer trainees volunteering. Interviews (n=22) were conducted in the period between completion of the ITT course and the start of the NQT year.

Interviews for trainees focused on how the trainee had prepared or would prepare to teach in three contexts:

1. A topic the trainee had taught on placement and was comfortable with teaching.
2. A topic the trainee had taught on placement and was less comfortable with teaching.
3. A topic to be taught in the next few weeks of their NQT year which they had not previously taught.

For each of these topics, the reasons for the topic being either more or less comfortable to teach were probed. Also for each of these areas, information was collected on how the HEI-based elements and school-based elements of their ITT course had contributed to the trainee preparing to teach those topics. In this context, the role of the SK audit was investigated. Finally the trainee was asked to identify their current CPD needs.

After listening to the recording and referring to any contemporaneous notes, findings from the trainee interviews were collated for each HEI case study.

Tutor interviews (only)

Interviews were carried out with eight tutors from the six case study HEIs. The schedule of questions covered five main areas: course philosophy, SK audit, mentor role/school based training, course structure and perception of continuing needs/transferability of skills. Interviews covered both generic and also institution/course specific questions.

This research project has raised awareness amongst HEI tutors of the project's focus, through sharing the aims of the project in a widely read publication (Lock, 2010) and at a conference. Such information, together with involvement in the interviews, may have made tutors consider and articulate their practice in a way that they might not have done before, which may impact on the validity of the method. In addition, at institutions where there were multiple tutors and where colleagues had been previously interviewed, discussion between them may have led to development of ideas before interview. Therefore the opinions expressed may be, to some extent, an artefact of the research methodology.

At all stages of the work, the research ethics requirements of the University of Birmingham and the other universities involved were met.

Findings and discussion

The main findings within each section are identified in bold and are followed by supporting evidence. Direct quotations from research data are identified as follows: H0 – document analysis; UT– university tutor questionnaires and interviews; and TT – trainee teacher questionnaires and interviews.

A. Qualifications and course intentions

Most HEI tutors said their trainees were being prepared to teach across the sciences to Key Stage 4 (age 16 – GCSE equivalent).

Most HEIs are engaged in preparing trainee teachers to teach all three sciences to age 16. The Training and Development Agency (TDA) requirement is that secondary courses prepare trainees to teach across the sciences at KS3 and their subject specialism beyond that point (TDA, 2010). From the data in Table 7 it is evident that 58 per cent of HEI tutors participating in this study go beyond the TDA requirement, in that they are preparing trainees to teach at least two sciences to KS4. It could be that ITT courses are providing what most schools appear to want and this strategy may increase the employability of trainees taught on these courses.

Table 7. Levels to which HEI training courses prepare to train teachers

Training to teach across the sciences to KS3 plus…	Number of HEIs	% of HEIs
Specialism to GCSE	6	8
Two sciences to GCSE	3	4
Dual award to GCSE	8	11
Specialism to GCSE + A level	21	29
Two sciences to GCSE + A level	10	14
Dual award to GCSE + A level	21	29
Other	2	3
No response	1	1

There is an imbalance of specialists on ITT courses with the number of biologists far exceeding chemists and physicists (approx 5:3:2).

While the majority of HEI tutors say they are preparing trainees to teach across the sciences to Key Stage 4, the number of biologists in the HEIs in our sample vastly outnumbers the number of physicists (1273 biologists, 836 chemists, 543 physicists). This imbalance in the number of specialists is likely to mean that there will be more biologists teaching outside their specialist area beyond Key Stage 3 including triple award science to GCSE. This has implications for SK and TSP development especially in the light of the Ofsted finding reported by DfE (2010b) that where the match between qualifications and subjects taught was good, the quality of teaching far exceeded cases where the match was poor.

DfE (2010b) also reports that a target of 25 per cent of science teachers should have a physics specialism by 2014. Based on our study, in which only 20 per cent of trainees have a physics specialism, a marked improvement in recruitment of physics specialists would be required to reach this target.

The minimum degree requirement HEI tutors accept for a trainee biological science teacher is higher than for a trainee physical science teacher.

Seventy-nine per cent of tutors regard class of degree as important (Table 8). However, tutor interviews revealed that other personal qualities such as overcoming personal difficulties, working with young people and previous successful teaching experiences also contribute to the makings of a teacher, leading to offers to applicants with third class degrees or lower. One possible explanation for this may be that physics and chemistry trainees coming through the SKE routes are accepted with initial qualifications that are a good deal lower than for trainees directly admitted to ITT courses.

Forty-two per cent of HEI tutors regard the institution awarding the degree as unimportant for acceptance on to an ITT course. This contrasts with the White

Paper's apparent focus on good quality graduates from Russell Group universities training to become teachers (DfE, 2010a).

Table 8. Importance of degree class and awarding institution (n, % in parentheses)

Importance of…	Unimportant	Important	No response
Degree class	15 (21)	57 (79)	0
Awarding institution	30 (42)	42 (58)	0

The minimum class of degree required for physical science trainees accepted on to courses appears to be lower than that for biological science trainees (Table 9). Over 50 per cent of tutors are prepared to accept physical science trainees with a third class degree or less, whereas only one-third of tutors are prepared to accept these classes of degree from biological science trainees. While this could be a reflection of the market and the relative abundance of people wanting to train as biology teachers, there might be serious implications arising from the proposal to cease funding for applicants with degrees lower than a 2.2 classification (DfE, 2010a, 2011) which are likely to reduce even further the supply of physical science teachers.

Table 9. Minimum class of degree required by HEI tutors for biological and physical science trainees

Minimum class of degree required by HEI tutors	For biological science trainees n (%)	For physical science trainees n (%)
First	0 (0)	0 (0)
Upper second	6 (8)	0 (0)
Lower second	35 (49)	26 (36)
Third	18 (25)	29 (40)
Ordinary	6 (8)	11 (15)
Other	4 (6)	4 (6)
No response	3 (4)	2 (3)

Confirmation that HEI tutors accept a lower class of degree for physical science trainees than for biological science trainees can be found in Smithers and Robinson's (2010) Good Teacher Training Guide.

Nearly one-third of trainees who regard themselves as physics specialists have a degree with limited identified physics content.

Data from the trainee questionnaire indicate that 31 per cent of physicists possess degrees with titles suggesting they have limited identified physics content. These titles include: Psychology, Applied Microbiology, Environmental Management, Archaeology, Forensics, Psychology and Sports Science. There are two principal ways in which possible limitations in SK might be addressed, by completing a subject knowledge enhancement (SKE) course either prior to their initial teacher training or during the HEI and school-based elements of an ITT course. Most HEI tutors (83 per cent) say they are prepared to make completion of an SKE course a condition of acceptance for candidates with degrees containing less than 50 per cent of the specialism they are training to teach, but trainee feedback on the quality and suitability of SKE courses is variable (see section C).

It is questionable whether a graduate with a degree containing less than 50 per cent of the specialist component can, following the completion of subject specific SKE and ITT courses, claim to be a specialist teacher of their subject to A level. A **specialist teacher** of physics, chemistry or biology should possess a degree in their specialism or a closely allied subject and study a specialist ITT course (physics, chemistry or biology) which would qualify them to teach their specialism to A level.

A science graduate with a degree containing less than 50 per cent of physics or chemistry but who has successfully completed specialist SKE (minimum 24 weeks) and ITT courses could be termed an **associate specialist teacher** of physics or chemistry qualifying them to teach physics or chemistry to Key Stage 4.

These categories of specialist teachers are similar in nature but different in detail from those described by SCORE (2011).

B. Addressing subject knowledge (SK) and topic specific pedagogy (TSP)

The HEI is the main location for formal engagement with SK and TSP.

The evidence for the main location for the development of SK and TSP residing within the HEI-based parts of the course was first obtained from the document analysis. In contrast, there is limited evidence of formal provision (timetabled teaching sessions) in support of SK and TSP on the school-based parts of the course via, for example, mentor meetings, written lesson appraisals or through observation of teachers.

Responses to tutor questionnaires and interviews also show that development of SK and TSP underpin the bulk of HEI-work with trainees. This finding reflects the importance of the HEI's contributions to SK and TSP development (House of Commons Children, Schools and Families Committee Report, 2010). This has implications for the proposal in the recent White Paper (DfE, 2010a) that less time is spent by trainees in HEIs as it raises the question of where trainees would obtain support for developing SK and TSP.

The document analyses illustrate ways in which HEI tutors view their role in relation to subject knowledge acquisition by trainees that vary from those who see it as having no part in a one-year initial teacher training course – '*…subject knowledge acquisition is your responsibility*' (H039) – through to those where sessions dedicated to subject knowledge acquisition are an integral part of the course. For the majority of institutions the focus is mainly on TSP but getting the subject knowledge right may be also be part of the course:

> *'Although we are not principally teaching content in university sessions, quite frequently, in attempting to teach a topic, students discover that they don't really understand part of the subject. Inevitably then the course is, at times, concerned with getting the science right.'* (H024)

HEIs provide formal sessions that are a mix of SK and TSP with greater emphasis placed on TSP.

HEI tutor (Table 10) and trainee (Figure 4) questionnaire data both show that the greatest proportion of time in formal HEI science method sessions is perceived to be devoted to TSP.

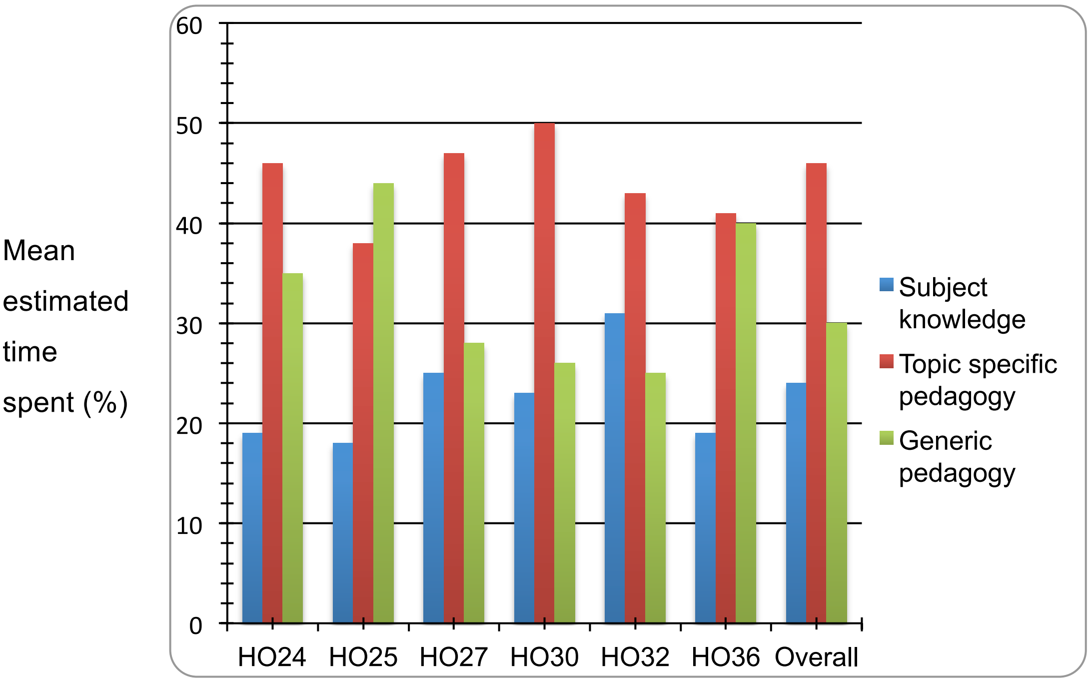
Table 10. Numbers of HEI tutors reporting on the proportion of time spent on addressing SK, TSP and generic issues

Proportion of time spent	**Number of HEI tutors reporting**		
	SK	**TSP**	**Generic issues**
>30%	53	85	44
<30%	47	15	56

Perceptions differ slightly between HEI tutors and trainees where the latter perceive more time spent on SK than generic issues while tutors perceive the opposite, although differences are small.

Within the six case study HEIs, there is variation in trainees' perceptions of the proportion of time devoted to the three separate components (Figure 4).

Figure 4. Trainees' perceptions of the proportion of science method time spent on addressing SK, TSP and generic issues in the six case study HEIs



There are two ways in which SK and TSP are addressed. One is where the primary focus is the subject knowledge, before addressing TSP, for example:

> '*Recap subject knowledge at Key Stage 3/4 in relation to patterns of reactivity and balancing equations. Think about differentiation and active learning. Chemistry for non-specialist sessions usually has a dual purpose, to revise one aspect of subject knowledge and to think about practical examples of an aspect of education that we have been looking at more generally.'* (UT32)

The other is where TSP is the primary focus, for example:

> '*To learn about perceptions students bring to the learning of particles. To critically evaluate a range of common science activities used to teach particle theory in order to give trainees some guiding principles into how to select appropriate activities to promote progression in students' learning. To develop, where necessary, subject knowledge in the area of particles up to Key Stage 4.'* (UT01)

Trainee interviews suggested that trainees felt reasonably well prepared for addressing SK and TSP in their NQT year irrespective of the approach adopted by the ITT course.

Document analysis, tutor and trainee questionnaires and interview responses indicated that most HEI-based sessions involved practical workshops organised in groups with mixed specialisms. HEI tutors and trainees also indicated that in formal elements of the course as a whole there is greater emphasis on TSP than on SK.

SK and TSP sessions in HEIs are mainly workshops led by tutors, most of whom stated they were actively engaged in science education research.

The document analyses show that SK and TSP sessions in HEIs are mainly workshops led by HEI tutors except for earth science, where visiting speakers were more commonly involved. While the House of Commons Children, Schools and Families Committee Report (2010) suggested that the majority of teachers were trained in HEIs where tutors were not research-active, in our sample most HEI tutors (66 per cent) reported themselves as being actively involved in science education research (Table 11).

Table 11. Research status of HEI respondents (RAE = Research Assessment Exercise).

Research status	Number of HEI tutors	% HEI tutors
Research-active in RAE	16	22
Research-active not in RAE	32	44
Not research-active	15	21
Teaching/admin only	9	13
No response	0	0

The amount of teaching time allocated to science appears to be very variable between HEIs.

The amount of HEI-based teaching time devoted to science method is very variable, with some HEIs devoting more than four times as many hours to science methods than others. Whilst some degree of variation might be appropriate in order to reflect the level of subject knowledge of the trainees recruited, this raises the question as to whether there should be more standardisation across HEIs of science method teaching time in one-year ITT courses. This could justify the call for wider research into how HEIs develop subject pedagogies in order to share practice (House of Commons Children, Schools and Families Committee Report, 2010). However, any additional teaching time required by HEIs may have implications for tutors' workloads.

How Science Works (practical and enquiry skills, critical understanding of evidence, applications and implications of science and communication), taught in separate sessions, does not appear to be a major identifiable focus in the HEI-based parts of courses.

Document analysis suggests that most courses devote a single, three-hour session to How Science Works. If this is the only time devoted to How Science Works in the HEI-based component, then the question arises as to whether this is adequate for engagement with the issues involved. How Science Works is a more recent curriculum innovation and some elements of it may be new, even to the graduates who have gone straight from school to university to an ITT course. Cultural understanding and examining the ethical and moral implications of science may not have featured prominently in many trainees' school experiences and this may have also been the case for some aspects of practical and enquiry skills. It is likely that in the school-based element of the course they would gain some experience of investigations. However, this experience is likely to be focused on assessment rather than pedagogies relating to How Science Works, which is broader than investigations. This calls into question the limited time devoted to How Science Works.

HEI tutors expect school mentors to monitor and set targets for SK and TSP.

As the school-based component in an ITT course takes up two-thirds of the year, it might be expected to make a major contribution to formally addressing SK and TSP development of trainee teachers. This does not appear to be the case.

The document analysis appeared to suggest that SK development is left to the student to address during the school-based component of the course, with mentors monitoring this development.

> '*Your science mentor in school may be able to help you with suitable references but don't expect them to "teach" you about the topic.'* (H036)

While TSP appears to have a clear place in formal HEI-based teaching, in all HEIs in our sample, its position in the school-based component is less clear in the documents analysed.

Most HEI tutors expect school mentors to monitor trainees' SK and TSP (71 per cent and 69 per cent respectively), while the expectation to set targets in the two areas is slightly less, at 56 per cent for SK and 65 per cent for TSP (Table 12).

Table 12. Tutor expectation of mentor involvement in monitoring and setting targets for SK and TSP (n, % in parentheses)

Do you expect mentors to:	SK n (%)	TSP n (%)
Monitor: Yes	51 (71)	50 (69)
Monitor: No	1 (1)	4 (6)
Monitor: No response	20 (28)	18 (25)
Set targets: Yes	40 (56)	47 (65)
Set targets: No	12 (17)	6 (8)
Set targets: No response	20 (28)	19 (26)

A minority of HEI tutors expect SK and TSP to be routinely addressed in formal mentor meetings.

Although HEI tutors expect TSP (61 per cent) to feature more than SK (56 per cent) in lesson feedback from school mentors (Table 13), this contrasts with research which suggests that mentors focus their writing, in roughly equal proportions, on class management and other generic issues, with a very limited focus on subject knowledge (Shallcross *et al*, 2002) and topic specific pedagogy (Lock, Soares and Foster, 2009).

Table 13. Tutor expectations of frequency of TSP and SK covered in lesson feedback by mentors (n, % in parentheses)

Frequency of addressing TSP and SK in lesson feedback	**TSP**	**SK**
	n (%)	**n (%)**
Every lesson	19 (26)	10 (14)
Most lessons	25 (35)	30 (42)
Few lessons	9 (13)	13 (18)
Never	0 (0)	0 (0)
No response	19 (26)	19 (26)

Only a small number of the 72 HEI tutors responding expect TSP (26 per cent) and SK (14 per cent) to be a routine part of the formal weekly meetings with mentors (Table 13) and the findings from trainees in the six HEI case studies confirm this. Data in Table 14 show that trainees see TSP (24 per cent) and SK (41 per cent) being addressed *only* at the trainee request. This suggests that HEI tutors may need to reinforce the routine development of TSP and SK through the formal weekly meetings with mentors.

Table 14. Addressing TSP and SK in formal mentor meetings (n, % in parentheses)

When is TSP and SK addressed in mentor meetings?	TSP		SK	
	HEI tutor	Trainees	HEI tutor	Trainees
	n (%)	n (%)	n (%)	n (%)
As part of every meeting	19 (26)	76 (31)	11 (15)	8 (3)
As/when mentor deems appropriate	33 (46)	102 (42)	37 (51)	86 (35)
Only at trainee request	1 (1)	59 (24)	5 (7)	101 (41)
Not at all	0 (0)	6 (2)	1 (1)	47 (19)
No response	19 (26)	2 (1)	18 (25)	3 (1)

HEI tutors help to support SK and TSP development for trainees on school placements, typically through two school visits to a trainee, where TSP and SK are included in discussions by 75 per cent and 63 per cent of tutors respectively.

In concluding this section of the findings, the view of Ofsted (2010, para 188, p 60) that SK is a relative strength for HEI providers due to the strong focus on ensuring trainees' SK is audited, developed and monitored closely throughout the ITT year must be regarded with a degree of scepticism.

C. Trainees' acquisition and use of SK and TSP

SKE courses led by ITT staff are perceived by trainees as more useful than those led by academics in science departments.

Trainees reported a range of SKE courses, including those led by ITT tutors, academic science departments and professional institutions. In telephone interviews, trainees who had attended 24 or 36 week SKE courses run by tutors involved in ITT were much more positive about the value of courses than those who had attended courses run by academic science departments. When the reasons for this dichotomy were explored, it emerged that trainees attending courses led by academic science departments were often taught with students on foundation courses and were dissatisfied with the relevance of the content and the level courses were aimed at:

> '...*we were put in with foundation students and thrown at what they were thrown at, which was kind of not what we needed, we needed* [SK enhancement] *more tailored to teaching...*' (TT30/61)

This could be because trainees need to see a more direct relevance to the material they are likely to teach.

Trainees view the SK audit process as inefficient and ineffective.

Guidance linked to QTS standards Q14 and Q15 states that trainees are:

> '…*able to teach all the science specified in the programme of study… at Key Stage 3. Trainees on 14–16 and 16–19 programmes should have the knowledge and understanding that would enable them to teach biology, physics or chemistry as a single subject at the appropriate level.'* (TDA, 2010)

HEIs appear to require their trainees to carry out a subject knowledge audit of National Curriculum content across the sciences at Key Stage 3 and 4, and where appropriate a specialist subject audit post 16. Tutors responding to the questionnaire indicated that subject knowledge audits were used to develop action plans and most tutors (71 per cent) claimed that audits were updated periodically.

Generally trainees found the subject knowledge audit process of limited value. Addressing any action plan detached from their immediate teaching commitment, so was considered inefficient in terms of workload and thus ineffective:

> '…*I just think it's* [SK development] *as you go along… pointless spending hours and hours on it when you might not even teach it during the year… so mine was very much as the lessons came, when I was told "Your next topic is going to be…"*' (TT27/66)

Most trainees focused on what they were about to teach irrespective of the outcome of the audit:

> *'You learn it to teach it. It's only once you're in the school when engrossed in the situation you can recognise which areas you really need to improve on.'* (TT27/83)

This finding for secondary trainee science teachers is similar to that found for primary trainees, where planning for and implementing teaching was the most effective strategy for acquiring and developing subject knowledge (Shallcross *et al*, 2002).

In summary, the evidence suggests that action plans *per se* are of limited value.

Most trainees identify the best time for developing SK as the point at which they are required to teach it.

Trainees were asked how much use they made in their classroom teaching of the SK learned in specific time periods. Data from trainees in the six HEI case studies (Table 15) indicate that at least 80 per cent of the trainees make 'lots' of use of SK learned during school-based periods compared to 66 per cent, at most, making 'lots' of use of SK learned during university-based science teaching sessions although many see the latter as useful.

Table 15. Reported use made by trainees of SK development

'Lots' of use made in classroom teaching of SK developed	% Trainees in case study HEIs					
	H024	H025	H027	H030	H032	H036
On school placements	91	93	80	80	89	95
In university sessions	51	40	51	66	66	38

It could be that the front-loaded nature of the HEI-based components, combined with the point in the course at which the questionnaires were administered, led to a lower percentage of trainees reporting making 'lots' of use of SK developed in HEI sessions in their teaching. This may indicate that the best time to address SK is during the school-based training where the development is directly targeted to specific areas trainees are asked to teach; a ‘point of need’ strategy advocated elsewhere (Lock and Soares, 2006) and reaffirmed in the trainee interviews:

> ‘…*I think it is important* [to address weaknesses in SK] *before you start your placement but I didn’t find I did it thoroughly or properly until I actually had to teach it… the most useful time was in the process as I was teaching it’* (TT27/76)

When interviewed, HEI tutors also indicated that the best time to address SK was when trainees came to teach a topic:

> ‘…*a lot of their subject knowledge* [development] *comes through preparing for specific lessons and specific topics while they are in school… it’s as if they do the subject knowledge on a ‘need to know’ basis while in school.’* (UT25).

These perceptions contrast with tutors’ views, from the questionnaire (Table 16), that the best time to address SK was during the HEI-based phase (28 per cent) rather than in schools prior to teaching (14 per cent). This anomaly might merit further exploration.

Table 16. Optimum time to address weaknesses identified through SK audit as reported by HEI tutors

Optimum time to address weaknesses identified through SK audit	**Number of HEI tutors**	**% of HEI tutors**
Undergraduate degree	3	4
Enhancement course	14	19
University-based ITT course	20	28
In schools prior to teaching	10	14
Other	8	11
No response	17	24

Trainees mainly use material resources to develop their SK whereas they use human resources to develop TSP.

Responses to two questions in the trainee questionnaire, one open (Table 17) and the other closed (Table 18), showed internal consistency with respect to the resources trainees use to develop SK. Responses to the open question show that the actions taken following SK audits tended to use more material-based resources than people-based resources for developing SK.

Table 17. Resources used for SK audit action by trainees at case study HEIs

Resources used for SK audit action	**% trainees**					
	HE024	HE025	HE027	HE030	HE032	HE036
Material-based	44	60	58	86	60	48
People-based	7	0	0	2	4	5
Both people and material-based	27	27	20	9	16	33
No response	22	13	22	3	20	14

This finding was consistent with closed question responses where trainees were asked to rank the six most important sources used when trying to address SK and TSP development from a given list (Table 18). The mean rank for each resource for SK and TSP development was calculated across the six case study HEIs. The rank order for SK development shows that the two most popular sources for SK development were material-based, confirming the findings of the open question. The mean rank order for SK and TSP development closely matched the HEI tutors' perceptions of trainee resource use.

Table 18. Ranking of resources identified by trainees used in SK and TSP development (high to low)

Ranking of resources used in SK development	Ranking of resources used in TSP development
1. Textbooks	1. Class teachers
2. Internet	2. HEI sessions
3. Class teachers	3. Mentor
4. Peers	4. Peers
=5. Teacher guides	5. Teacher guides
=5. Technicians	6. Internet
7. HEI sessions	7. HEI tutors
8. Mentors	8. Textbooks
9. CDs and DVDs	9. Technicians
10. Science National Strategy	10. Science National Strategy
11. Journals	11. Journals
12. HEI tutors	12. CDs and DVDs

Material-based resources ranked high for development of SK and human resources for the development of TSP.

Trainees rate peers high in the rank order of resources used to access both SK and TSP.

For both SK and TSP development, 'peers' are ranked in the top four of resources used. This may be because trainees work together in groups in many of the formal and informal HEI-based components; where trainees are paired on school placements, they may discuss SK and TSP as well as jointly planning lessons and sharing resources.

The classroom teacher is an important resource for SK and TSP development.

The classroom teacher is the top ranked resource for TSP development and third for SK, above mentors and HEI tutors. The reason the classroom teacher is ranked more highly may be that for any given class, the teacher is likely to have the best knowledge of the pupils, the level they are working at and resources available in the school.

It could also be that classroom teachers are ranked more highly than mentors or HEI tutors because trainees are aware of the assessment roles of mentors and tutors (Youens and McCarthy, 2007) and may be concerned that consultation about SK and TSP could affect them adversely.

The dependence on classroom teachers might require HEI tutors to devote time to working with whole departments, providing guidance on how best to support trainees with SK and TSP development. '*Training departments'* are mentioned in some HEI documentation, but in most cases appear not to be associated with any formal training or, at best, dependent on informal cascading from mentors. Training departments might be components within the '*teaching schools*' proposed in the recent White Paper (DfE, 2010a).

In one HEI this notion of a training department has been developed to a position where some class teachers have been specifically trained to provide coaching in SK and TSP development. These trained coaches provide SK and TSP support for trainees in the topics they are about to teach. Such an arrangement may provide a mechanism for formalising classroom teacher support at 'point of need', enhancing the support provided by the mentor.

HEI sessions rank highly as a resource for developing TSP.

Data in Table 18 show that HEI sessions are highly ranked as a resource used in TSP development. These findings resonate strongly with evidence offered by Ofsted (2010). The data also suggest a mismatch in the ranking of HEI tutors and HEI sessions with respect to both SK and TSP. This may be because the contribution to both SK and TSP by HEI tutors is mediated through taught sessions and not individually. This contrasts with the individual contributions made by mentors and class teachers to individual trainees.

HEI tutors organise sessions where trainees work in small groups, of between two and ten, as one way of developing subject knowledge and topic specific pedagogy. Such sessions are mostly used in the period between school practices when those trainees who have taught a topic can share their 'expertise' in SK and TSP. It is, however, rare for these sessions to be formally validated by HEI tutors. The value of such sessions may be called into question with respect to the levels of accuracy with the SK and appropriateness of associated TSP; a point raised by Shallcross *et al* (2002) where primary trainees, engaged in peer support, perpetuated misconceptions.

Trainees reported that virtual learning environments (VLEs) and pages on social networking sites set up to share information between trainees were found to be valuable. Tutors recognised that these were being used by trainees but were unable to identify the extent of use or to provide validation of the shared materials.

In summary, the formal engagement with SK and TSP in school-based training is limited and their acquisition appears to be complex and addressed informally.

D. Trainees and the NQT year

For science NQTs, physics topics were a high priority for CPD courses in their first year of teaching.

Trainees (n=245) were asked to identify three courses for further development in their NQT year. Physicists and chemists identified Key Stage 5 content in their specialist and Key Stage 4 content in their non-specialist areas. This may reflect the greater likelihood of physicists and chemists being asked to teach post 16 classes in their NQT year and teaching outside their specialism to Key Stage 4. Biologists, in contrast, may be less likely to be required to teach post 16 biology, and more likely to be asked to teach all sciences to 16.

Table 19. Course topics nominated by trainees for development in NQT year

Course type	Topic	Number of trainees
Science-based courses	Biology	36
	Chemistry	59
	Physics	86
	HSW	5
	Learning outside classrooms	10
	Practicals (unspecified)	37
	Total	**233**
Generic courses	Behaviour management	75
	Special Educational Needs	34
	Assessment (AfL, APP)	87
	Differentiation	37
	Gifted and Talented	21
	EAL	8
	Other	167
	Total	**429**

Of the science-based courses identified, physics topics were most in demand (Table 19). Biology specialists were much more likely than their chemistry and physics counterparts to identify courses outside their specialism; this may reflect the greater likelihood of biologists having to teach outside their specialism in the NQT year.

Although the document analysis shows that How Science Works was typically covered in a single science method session, it is surprising that there was little demand for courses in teaching this aspect in the NQT year.

The development of subject knowledge and topic specific pedagogy can, and should, be a long term and continuous process through structured early professional development building on the ITT year. Such progression and continuity within and between initial, induction and in-service training should form a part of the career development for all teachers.

Trainees identify behaviour management and assessment as priorities for CPD courses in their NQT year.

Data in Table 19 show that trainees were nearly twice as likely to identify generic courses rather than science-based courses. The most popular generic courses were linked to assessment issues, with Assessment for Learning (AfL) and Assessing Pupil Progress (APP) frequently identified, closely followed by behaviour management (Table 19).

These findings suggest that CPD providers should focus on courses that address:

- Behaviour management.
- AfL and APP.
- KS4 physics and chemistry content for non-specialists.
- KS5 content for specialists in physics and chemistry.

Processes to address SK and TSP are considered by trainees and HEI tutors to be transferable to unfamiliar topics.

In the questionnaire responses few trainees identified specific science topics on which courses should focus in their NQT year. This could be because their experience with topics studied during the ITT year gives them the confidence to apply the processes used in planning for teaching to unfamiliar science topics.

Trainees who were interviewed confirmed that when asked to teach unfamiliar topics in their NQT year they would adopt the same approaches that they learned for addressing SK and TSP during their ITT course. Some also referred to specific tools that provided a model for developing SK and TSP.

> *'…rather than necessarily teaching us a topic it* [HEI-based component] *has taught us where to look for help.'* (TT36/168).

Interviews with HEI tutors indicated an expectation that trainees would approach teaching unfamiliar topics in their NQT year in broadly the same way as they addressed topics during the ITT course.

HEI tutors generally regarded the NQT year as a continuation of the ITT year and suggested that a high level of support is needed to make the NQT year successful. Such support might be similar to the additional mentoring provided by the ‘Starting Out programme’ (Learning and Skills Network, 2010), and HEI tutors, through involvement in such a programme, could provide progression and continuity from the ITT year into the induction year.

Conclusion

Trainees and HEI tutors suggest that a limited number of topics addressed during their ITT course provide a heuristic device (Childs and McNicholl, 2007) or models of working which can be applied when they encounter unfamiliar topics during their NQT year and beyond. These models of working require human resources for support that include HEI tutors, mentors and classroom teachers. HEI tutors have a role in providing CPD support for mentors and classroom teachers with respect to developing the mentoring skills necessary to help secondary trainee science teachers' acquisition of subject knowledge and topic specific pedagogy.

Further research is required into the apparent differences in the teaching time and the content in the HEI and the school-based parts of ITT courses, as well as the needs of NQTs at the end of their induction year with respect to subject knowledge and topic specific pedagogy.

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References

Berry, A., Loughran, J. and van Driel, J.H. (2008) Revisiting the Roots of Pedagogical Content Knowledge, International Journal of Science Education, 30 (10) 1271–1279.

BOS (2010) Bristol Online Surveys. www.survey.bris.ac.uk (accessed 3rd January 2010 and personal communication).

Burn, K., Childs, A. and McNicholl, J. (2007) The potential and challenges for student teachers' learning of subject-specific pedagogical knowledge within secondary school subject departments. The Curriculum Journal, 18 (4) 429-445.

Bucat, R. (2004) Pedagogical content knowledge as a way forward: applied research in chemistry education. Chemistry Education Research and Practice, 5 (3) 215–228.

Childs, A. and McNicholl, J. (2007) Science teachers teaching outside of subject specialism: challenges, strategies adopted and implications for initial teacher education. Teacher Development, 11 (1) 1–20.

Creswell, J.K. (2009) Research design: Qualitative, quantitative, and mixed methods approaches. London, Sage.

Department for Business Innovation and Skills (2010) Science and Mathematics Secondary Education for the 21st Century: Report of the Science and Learning Expert Group. London, HMSO.

DCSF (2008) Talking Science Pedagogy. www.standards.dcsf.gov.uk (accessed 19th February 2010).

DfE (2010a) The Importance of Teaching, the Schools White Paper 2010. London, The Stationery Office.

DfE (2010b) Educating the next generation of scientists. London, The Stationery Office.

DfE (2011) Training our next generation of outstanding teachers: an improvement strategy for discussion. London, The Stationery Office.

DfES (2006) The Science, Technology, Engineering and Mathematics (STEM) Programme Report. London, HMSO.

Eraut, M. (2000) Non-formal learning and tacit knowledge in professional work. British Journal of Educational Psychology, 70 (1) 113–136.

Geddis, A.N. (1993) Transforming subject-matter knowledge: The role of pedagogical content knowledge in learning to reflect on teaching. International Journal of Science Education, 15 (6) 673–683.

Grossman, P.L., Wilson, S.M. and Shulman, L.S. (1989) Teachers of substance: Subject matter knowledge for teaching. In: Knowledge base for the Beginning Teacher. (ed) Reynolds, M.C. New York, Pergamon.

GTTR (2009) Guide for applicants. Cheltenham, UCAS and www.gttr.ac.uk (accessed 9th December 2009).

House of Commons Children, Schools and Families Committee (2010) Training of Teachers: Fourth Report of Session 2009–10, Volume 1. London, The Stationery Office.

Institute of Physics (2002) Physics Teacher Supply: A Report of the Institute of Physics. London, Institute of Physics.

Kind, V. (2009) Pedagogical content knowledge in science education: perspectives and potential for progress. Studies in Science Education, 45 (2) 169-204.

Learning and Skills Network (2010) Starting Out: mentoring support for early career maths and science teachers. www.earlystemcareer.org.uk/Pages/Default.aspx (accessed 13th December 2010).

Lock, R. (2010) Topic specific science subject knowledge and pedagogy in one year post graduate initial teacher training courses. Science Teacher Education, 57, 28–30.

Lock, R. and Soares, A. (2005) The induction year experience: a route to improving recruitment and retention. Education in Science, 214, 32–33.

Lock, R. and Soares, A. (2006) Supporting student teachers' knowledge and approaches to teaching and learning the physical sciences. School Science Review, 88, 322, 29–36.

Lock, R., Soares, A. and Foster, J. (2009) Mentors' written lesson appraisals: the impact of different mentoring regimes on the content of written lesson appraisals and the match with pre-service teachers' perceptions of content. Journal of Education for Teaching: International Research and Pedagogy, 35, (2) 133–143.

Loughran, J., Mulhall, P. and Berry, A. (2008) Exploring Pedagogical Content Knowledge in Science Teacher Education. International Journal of Science Education, 30 (10) 1301– 1320.

NFER (2006) Mathematics and science in secondary schools. The deployment of teachers and support staff to deliver the curriculum. Research report no.708. NFER Trading Ltd.

Nilsson, P. (2008) Teaching for Understanding: The complex nature of pedagogical content knowledge in pre-service education. International Journal of Science Education, 30 (10) 1281–1299.

Ofsted (2010) The Annual Report of Her Majesty's Chief Inspector 2009/10. London, The Stationery Office.

Roberts, R., Gott, R. and Glaesser, J. (2010) Students' approaches to open-ended science investigation: the importance of substantive and procedural understanding. Research Papers in Education, 25 (4) 377–407.

Schwab, J.J. (1978) Science, Curriculum and Liberal Education. Chicago, Chicago University Press.

SCORE (2011) Subject specialist teaching in the sciences: definitions, targets and data. London, Gatsby Technical Education Projects.

Shallcross, T., Spink, E., Stephenson, P. and Warwick, P. (2002) How primary trainee teachers perceive the development of their own scientific knowledge: Links between confidence, content and competence? International Journal of Science Education, 24 (12) 1293–1312.

Shulman, L.S. (1986) Those who understand: Knowledge growth in teaching. Educational Researcher, 15 (2) 4–14.

Smithers, A. and Robinson, P. (2010) The Good Teacher Training Guide 2010. Buckingham, Centre for Education and Employment Research.

The Royal Society (2007) A ‘state of the nation’ report: The UK’s science and mathematics teaching workforce. London, The Royal Society.

TDA (2010) QTS Standards Guidance www.tda.gov.uk/trainee-teacher/qts-standards.aspx (accessed 13th December, 2010).

Van Driel, J.H., De Jong, O. and Verloop, N. (2002) The development of preservice chemistry teachers' pedagogical content knowledge. Science Education, 86, (4) 572–590.

Van Driel, J.H., Verloop, N., and de Vos, W. (1998) Developing science teachers' pedagogical content knowledge. Journal of Research in Science Teaching, 35 (6) 673–695.

Van Dijk, E.M., and Kattmann, U. (2007) A research model for the study of science teachers' PCK and improving teacher education. Teaching and Teacher Education, 23 (6) 885–897.

Youens, B. and McCarthy, S. (2007) Subject knowledge development by science student teachers: The role of university tutors and school-based subject mentors. Research in Science and Technological Education, 25 (3) 293–306.

Glossary

AfL	Assessment for Learning
APP	Assessing Pupil Progress
ASE	Association for Science Education
ATSE	Association for Tutors in Science Education
CPD	Continuing Professional Development
DfE	Department for Education
GCSE	General Certificate of Secondary Education
GTTR	Graduate Teacher Training Register
HEI	Higher Education Institution
INSET	In-service Education and Training
ITT	Initial Teacher Training
KS	Key Stage
KS2-3	Key Stage 2–3 (age 9–14)
KS3-4	Key Stage 3–4 (11–16)
KS3-5	Key Stage 3–5 (11–18)
NQT	Newly Qualified Teacher
PCK	Pedagogical Content Knowledge
QTS	Qualified Teacher Status
RAE	Research Assessment Exercise
SK	Subject Knowledge
SKE	Subject Knowledge Enhancement
TDA	Training and Development Agency
TSP	Topic Specific Pedagogy
TTRB	Teacher Training Resource Bank
VLE	Virtual Learning Environment

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