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Insights from a subject knowledge enhancement course for preparing new chemistry and physics teachers

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ABSTRACT A recent Government response to shortages of new physics and chemistry teachers is the extended subject knowledge enhancement (SKE) course. Graduates without a physics or chemistry bachelor degree are prepared by an SKE course to enter a Postgraduate Certificate in Education (PGCE) programme to become science teachers with a physics or chemistry specialism. SKE courses challenge common assumptions about the nature of subject knowledge for teaching and who should teach it: school science educators or scientists? This article shares the SKE course model developed and taught by the Science Education team at Liverpool John Moores University, and some early insights into supporting subject knowledge development.

Setting the scene

A variety of initial teacher education (ITE) routes for prospective secondary chemistry or physics teachers exist. The most common ITE route is a 1 year Postgraduate Certificate in Education (PGCE) course, aimed at graduates with a bachelor degree in a science subject. PGCE courses are usually led by a university in partnership with schools. To be awarded qualified teacher status (QTS) in England and Wales, a student teacher must demonstrate they have met a series of QTS Standards (revised for September 2012 onwards). Standard 3 states that a teacher must '*demonstrate good subject and curriculum knowledge*' (Department for Education, 2012), and specifically must:

- *have a secure knowledge of the relevant subject(s) and curriculum areas, foster and maintain pupils' interest in the subject, and address misunderstandings*
- *demonstrate a critical understanding of developments in the subject and curriculum areas, and promote the value of scholarship*

The Government requires PGCE courses to provide 120 days of school-based development, typically leaving 60 days of university-based development. The university-based days commonly focus on aspects of science education pedagogy and critical engagement with educational literature, with limited time available for in-depth exploration and development of subject knowledge. The Government has stated an intention that new teachers should hold at least a 2 : 2 class bachelor degree (Department for Education, 2010). This policy suggests that degree classification is seen by policy makers to be a good indicator of potential to be an effective teacher. Difficulties with recruiting sufficient teachers has led to the creation by the Government of extended subject knowledge enhancement (SKE) courses, aimed at graduates with insufficient chemistry or physics at bachelor degree level to enter confidently into a PGCE course (Department for Education, 2013). This has resulted in an ITE route that is presented officially as 6 months to 1 year SKE (i.e. developing knowledge of the subject) followed by 1 year PGCE (i.e. developing knowledge of how to teach the subject).

Why is this important?

The SKE course concept challenges the conventional wisdom that a bachelor degree in a subject is a prerequisite to being an effective teacher of that subject. It also raises questions about to what extent science teachers are, or should be, primarily teachers of science or teachers of biology, chemistry or physics. At least one of the authors of this article expressed scepticism that it would be possible for someone without a physics degree to develop the physics understanding needed to thrive on a PGCE course, and the idea can polarise opinions among educators. Analysis of research has shown that a science teacher's bachelor degree classification (i.e. the awarded *grade* of achievement) has a less significant effect on pupils' learning outcomes than some educational policy makers appear to expect, with factors such as quality of relationships with pupils appearing to exert a more significant influence (Hattie, 2009). What is clear is that, regardless of level of academic qualification, the quality of a teacher's understanding of fundamental concepts in a subject plays an important role in enabling a teacher to deal effectively with pupils' misconceptions (van Driel, Verloop and de Vos, 1998), and this understanding cannot be achieved solely through a subject knowledge audit-driven approach (Lock, Salt and Soares, 2011).

Since SKE courses started at Liverpool John Moores University (LJMU), 67 students have gained QTS having gone through the SKE-then-PGCE route. This article aims to share with science educators how the SKE course model has evolved at one university and to stimulate thinking about the nature and development of science subject knowledge for teaching. A future article will share research by LJMU course tutors into SKE students' experiences of developing subject knowledge and how this has informed their practice in schools.

What is teacher subject knowledge?

Even a cursory look at the literature about teacher subject knowledge reveals that the answer to this question is complex and contentious. What follows is by necessity a brief and selective guided tour that is intended to provide some food for thought. The authors referred to are by no means the only people researching and writing on this topic, but we suggest that they form a starting point for a deeper exploration of thinking about subject knowledge.

Much of the discussion over the last 20 years about the nature of subject knowledge for teaching takes as a starting point that there is a clear difference between scholarly science knowledge (the realm of the scientist) and school science knowledge (the realm of the teacher). Perhaps the most commonly cited example is a model proposed by Lee Shulman, in which he referred to subject knowledge as *content knowledge* (Shulman, 1986). Shulman proposed that content knowledge can be divided into three categories:

- **Subject matter content knowledge (SMCK)** consists of the '*amount and organization of knowledge per se in the mind of the teacher*' (p. 9). This involves not just knowing the 'facts' of science, but also understanding the rules and principles by which these 'facts' are organised and amended. So, chemistry SMCK is the area of chemistry subject knowledge that is common to both a scholar of chemistry and a teacher of chemistry.
- **Pedagogical content knowledge (PCK)** '*goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge* for teaching … *it embodies the aspects of content most germane to its teachability*' (p. 9) and is the area of knowledge distinctive to teachers, such as knowledge of appropriate analogies and demonstrations, and what makes understanding of particular concepts challenging for learners.
- **Curricular knowledge (CK)** includes knowledge of the programmes and routes that can be followed, and the resources that can be utilised. Shulman described it as '*the pharmacopeia from which the teacher draws those tools of teaching that present or exemplify particular content and remediate or evaluate the adequacy of the student accomplishments*' (p. 10).

The concept of *PCK* is often used by educators. The authors of this article have participated in various meetings and conferences with teachers where PCK is referred to in an uncritical way and with some variation in meaning. Among those who use Shulman's language there appears to be consensus around two specific points (van Driel *et al*., 1998):

- PCK is subject-specific and therefore different from knowledge of general pedagogy;
- PCK is about how particular topics can be *taught* rather than 'pure' subject knowledge in itself.

In the language of Shulman (1986), the SKE-then-PGCE route can be interpreted as development of SMCK (SKE course) and then development of PCK and CK (PGCE course), an interpretation implied by much of the language used to market these courses.

There are criticisms of the lack of evidence proposed by Shulman to support the idea of PCK as a distinct category of knowledge, with some instead suggesting that PCK emerges through a process of blending general pedagogy with content.

Banks, Leach and Moon (1999) propose that teachers' subject understanding can also be divided into three categories:

- **Subject knowledge** (i.e. scholarly knowledge);
- **School knowledge** which is created through a process of *transposition* of scholarly knowledge into a restructured and linear form that can be accessible by, and taught to, children;
- **Pedagogic knowledge** which is knowledge of teaching and learning, and an understanding of the relationship between subject knowledge and school knowledge.

These three categories interact dynamically along with the *personal constructs* of the teacher, which emerge from the teacher's prior experiences, beliefs and knowledge of teaching. It is interesting to compare the linear structure of *science school knowledge* created by teachers with the messiness and non-linearity of how scientists actually work. One of the criticisms that can be made about school science is the neat and tidy picture it presents of scientific progress taking place in an inevitable, planned and orderly way (a picture some scientists themselves have been happy to foster!). As with Shulman (1986), the Banks *et al.* (1999) model claims that there is something distinctive about the subject understanding held by science teachers, although it is unclear what the criteria are for deciding whether an idea or model is an example of *subject* or of *school* knowledge.

Models of teacher subject knowledge such as those of Shulman (1986) and Banks *et al.* (1999) are criticised by some for ignoring the effect of interaction with learners on the development of subject understanding. These models imply that subject knowledge and its development resides with individuals and can be 'boosted', 'enhanced' or 'audited' (i.e. it is *objective*). This *objectivist* view of knowledge is criticised by those who adopt social models of learning (e.g. *socio-constructivist* models) and for ignoring the essentially pedagogic nature of language. Claiming to understand a scientific concept requires the use of language, which is an act of communication, i.e. a pedagogical act. For example, when a scientist explains to colleagues some aspect of her research into the electrical properties of graphene, her explanation is tailored according to who and what the explanation is intended for: explanations always have someone else in mind. As McEwan and Bull (1991: 324) put it:

> *[s]cholars must be concerned with the comprehensibility and teachability of their assertions, that is, with whether those 'representations' can find a meaningful place in others' webs of belief ... the justification of scholarly knowledge is inherently a pedagogical task ...*

This suggests that what is commonly called *subject knowledge for teaching* may be more to do with how experienced and adept someone is at formulating effective explanations for particular groups of learners (e.g. secondary pupils) rather than a body of knowledge that is unique to people labelled as teachers. This experience comes from interacting with others and will be driven by context. Some views of teacher subject knowledge regard these factors as central to how teachers develop their knowledge. Ellis (2007: 447) proposes that subject knowledge should be treated as '*complex, dynamic and as situated as other categories of teachers' professional knowledge*'. Ellis highlights the significance of new teachers participating in what Wenger (1998) described as a *community of practice*, where subject understanding is constructed (or *negotiated*) through interaction with peers and with learners. This is a long way from the simple model of teacher subject knowledge as something that can be taught to individuals as a distinct subject in a context far removed from the one they will be using it in.

These models of subject knowledge development (and others) continue to challenge our thinking about the SKE and PGCE courses and how to support student teachers effectively.

Designing the SKE course

When we first started to plan the course, one of the options considered was to base some of it in the Science Faculty in LJMU, with some supervision and coordination to be provided by the Education Faculty. This idea was discounted owing mainly to concerns about making sure the course content and teaching approaches used would be suitable to support students to prepare them to become science teachers rather than scientists. Looking back at those early discussions, it is striking how this important decision was based on experience and professional judgement as school science education practitioners, rather than careful consideration of research evidence or other literature. In our experience, this decision has been vindicated and recent studies have shown that students prefer SKE courses to be run by ITE tutors (Lock *et al*., 2011). If subject knowledge for teaching really can be categorised in the way suggested by Shulman (1986) then choosing to delegate subject knowledge development to the relevant academic university departments should be reasonable, with appropriate guidance given to the departments concerned about what to cover. Experience and feedback from other universities that have taken this approach suggest otherwise. At an early stage it was decided to create a course that would be validated by the university as a graduate diploma, which would be worth 120 credits at National Qualifications Framework Level 6 (in the NQF, Level 6 is equivalent to the final year of a BSc). What made the course Level 6 was the emphasis on critical engagement with subject knowledge and the level of independent learning required. The level of chemistry or physics covered was aimed at Levels 2–4, that is GCSE-level understanding of key concepts and building up to A-level and beyond.

The SKE course ran for the first time at LJMU in 2008/9, with a course structure requiring all of the students to study both chemistry and physics during the first semester (September to December) and then choosing one subject to specialise in for the second semester (January to May). Experience and student feedback informed the decision to develop the course further for 2009/10 so that students opted to be chemistry or physics specialists from the start of the course but they still studied both sciences during the first semester. For the 2010/11 academic year onwards, both sciences were treated as separate routes from the beginning to enable students to have more time and support to develop their subject understanding. The numbers of students recruited each year is shown in Table 1.

SKE course students start off as candidates for a PGCE course and all have at least one science A-level. During the PGCE selection day, the course team makes an assessment about candidates' subject experience (a process that leads to much discussion within the course team about how to judge meaningfully someone's subject knowledge during a selection process). An offer of a PGCE place may then be made, conditional on successfully completing an extended SKE course first. During 2008/9 and 2009/10, a large proportion of candidates entered the course with psychology or sports sciences backgrounds. In the last 2 years we have seen an increasing number of students enter the SKE course with biological sciences backgrounds, in response to the reduction in number of ITE places available for biology.

Table 1 Numbers of SKE students at LJMU by route

Academic year	Number on chemistry route	Number on physics route
2008/9	9	7
2009/10	12	12
2010/11	19	11
2011/12	25	12

Course evaluation feedback from the first two cohorts of SKE students was consistent about the desire to integrate pedagogical considerations into the course and for more support with the amount of independent learning required. The version of the SKE course that has run for the last 2 years incorporates tutor and student feedback and experience and is summarised in Figure 1.

Different modules are phased in at different times so that the students have a chance to develop confidence and to focus on the basic skills and understanding needed for later in the course.

Essential Chem/Phys Concepts and *Further Chem/Phys Concepts*

The *Essential Chem/Phys Concepts* and *Further Chem/Phys Concepts* modules form the backbone of the course and cover a range of key concepts and ideas in the relevant subject (see Table 2).

The assessment involves an end-of-module examination and a series of assignments where students work independently on questions or

Table 2 Example topics for the main physics/chemistry modules

Physics	Chemistry
Forces and Motion	Atomic structure
Energy	The Periodic Table
Wave and particle models	Equilibrium
Electricity and electromagnetism	Chemistry of carbon

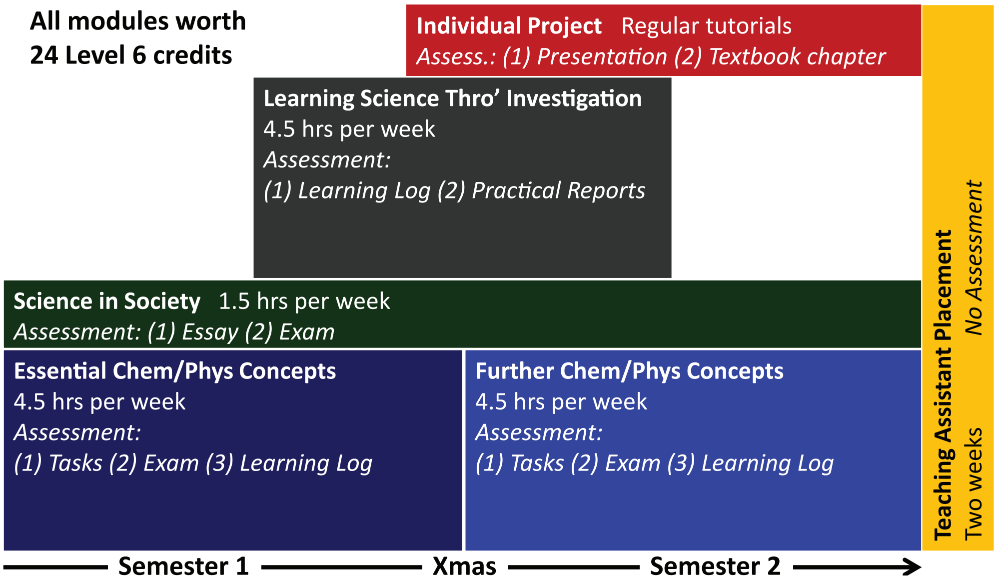

Figure 1 The current extended SKE course structure at LJMU

activities and submit a written piece of work. A key component of the Level 6 aspect of the course is a learning journal, kept by the students, that is assessed at various points in different ways in both modules and in the *Learning Science Through Investigation* module. This includes submission of sections or digests of the journal and critical incidents tasks, which demonstrate the students' ability to reflect on their learning.

Science in Society

The tutor team decided at an early stage that the SKE students should explore science and society issues alongside learning the chemistry or physics content. This module explores some of the current issues in science that are likely to have a major impact on society, while also providing an opportunity to learn aspects of physics or chemistry concepts that might not be covered in other modules. In addition, this module provides the opportunity to develop some subject understanding of biology. Example topics explored include:

- development and use of smart materials;
- genetically modified organisms;
- evaluating risk and the tentative nature of scientific knowledge in decision-making;
- the Standard Model and the Large Hadron Collider at CERN.

Assessment is through an extended essay and an end-of-module examination.

Learning Science Through Investigation

Practical work forms the core of this module, which provides students with an opportunity to develop scientific and pedagogical understanding, and practical skills, through a series of extended laboratory-based physics or chemistry practical tasks. Assessment is through writing of practical reports and extracts from the ongoing learning journal.

Individual Project

To support the students in synthesising their subject knowledge and applying it in a pedagogical context, the *Individual Project* module involves the students individually choosing a scientific context and then developing a textbook chapter. The chapter is aimed at high-attaining GCSE/AS-level students and would support learners to develop knowledge of physics or chemistry applicable to that context. Example topics from recent cohorts include:

- scuba diving;
- amusement park rides;
- using nanotechnology in cancer diagnosis and treatment;
- poisons and pharmaceuticals.

The first assessment task requires the students to present their chapter approach and rationale to their peers. This allows the students to collect peer feedback on their chapter structure and how they have chosen to break down the science topics, which they can use to produce their final printed chapter a couple of weeks later.

Teaching Assistant Placement

At the end of the course, the students spend 2 weeks in a school science department in a learning assistant role. This activity is not assessed (although a report is completed by the school) and allows the students to develop insights into the work of science teachers, and to relate their own learning to the misconceptions and difficulties experienced by pupils. With the support of the school-based mentor, some students may have the opportunity to teach part of a whole lesson (although this is not a requirement of the placement) and all students have the opportunity to use the experience to gather evidence towards achieving QTS during the PGCE year.

Lessons learned

The last 4 years have involved a learning journey for the LJMU Science Education team as we have engaged with the wide-ranging needs of SKE students. Some of the key lessons we have learned are:

- The students report that they see themselves as student *teachers* on a 2 year journey to achieving QTS, and not simply as students of physics or chemistry in preparation for subsequently learning to teach. We perhaps approached the first year of the SKE course as focusing on SMCK (in the language of Shulman (1986)) or *subject knowledge* (in the language of Banks *et al.* (1999)) and did not appreciate the extent to which the students wanted to learn *how* to teach as much as learning *what* to teach. One student explained that he was very aware of what he described as the 'oncoming train' of the PGCE course and having to help children learn the physics concepts he himself was struggling with.
- Developing subject knowledge *for teaching* requires integral consideration of pedagogical issues. The key additional step is to make these pedagogical issues *explicit*. We have found that the misconceptions held by SKE students are the same misconceptions held by pupils and non-SKE PGCE students. Articulating and analysing your own misconceptions is a vital aspect of developing your scientific understanding, and simultaneously requires critical consideration of how others might learn. For the lead author, working with SKE students has brought home the full implications of what McEwan and Bull (1991) claimed about the pedagogic nature of subject knowledge and has led us to question how models such as those of Shulman (1986) and Banks *et al.* (1999) can be used to inform ITE practice.
- Student feedback shows that one of the most effective teaching and learning approaches used appears to be peer-teaching. This is carried out in various ways and will be explored in more depth in a later article. As the team has gained experience with each year of the SKE course, there has been more emphasis placed on the tutor and student group as a *community of practice* (Wenger, 1998). Activities where students, individually and in groups, take it in turns to teach peers have a powerful effect on students' understanding of fundamental science concepts through requiring them to focus on how to explain concepts to others. Some students have reported that they struggle to make effective use of their independent learning time and peer-teaching has helped some of them to address this. We have found through peer-teaching that many students prefer to focus on developing their understanding of a topic when they are also required to use it 'for real' in a teaching situation. (Lock *et al.* (2011) report that this seems to apply in general to most ITE students.) Peer-teaching appears to be effective partly because it leads to questions from peer-learners that reveal unanticipated misconceptions and enables the peer-teachers to practise explanations in a 'safe' and supportive setting. Supporting students to work in this way requires tutors to reflect on their role in scaffolding activities, modelling good practice explicitly and supporting students to reflect on how they learn.
- An increasing number of our student teachers are career-changers and some find it daunting to return to education after a period of employment. Formal evaluation evidence suggests that the SKE course allows students, who have valuable prior experiences to bring to the teaching profession, to boost their confidence through rediscovering and practising effective learning approaches.
- Comparison of final grades awarded for QTS Standard Q14 (the 'subject knowledge' Standard replaced by Standard 3 from September 2012) at the end of the PGCE course shows that SKE students' Q14 attainment is consistent with that of non-SKE PGCE students. For the 2011/12

academic year, over 80% of SKE and non-SKE PGCE students at LJMU were graded by schools as '1' against Ofsted criteria for Q14, with no students from either group receiving a '4'. We are not claiming that assessment of Q14 has been an in-depth analysis of a student teacher's subject understanding. However, Q14 was intended to be the threshold to be crossed to be awarded QTS as far as subject knowledge is concerned, and based on this criterion, school-based mentors do not generally identify SKE-route PGCE students as lacking sufficient subject knowledge. The extent to which this is dependent on the nature of the schools that accept SKE-route PGCE students on school-based placements, and the quality of school-based mentoring they experience, is an aspect to be researched in depth by the LJMU team soon.

What next?

This article has been intended to provide some food for thought about science teacher subject knowledge and SKE courses through sharing one approach taken in one institution. In a future article we intend to discuss in more depth our experiences of using context-based and peer-teaching approaches, and to report the results of a research project to evaluate the effectiveness of the course and the progression of former SKE students in the teaching profession.

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