'Really disliked it at A-level. Never truly understood it.' Identifying topics in which chemistry teachers lack confidence

David Read and Stephen M. Barnes

Abstract Chemistry is a challenging subject for its students and those who teach them. A teacher's subject matter knowledge (SMK) is the foundation on which their pedagogical content knowledge (PCK) is founded, and is the basis of successful teaching. Flawed SMK can result in teachers holding misconceptions that are then transferred to students. In this article, we report the results of a survey of chemistry teachers that probed their views of their own SMK, its development and its importance. Key findings are the identification of electrochemistry as the topic that teachers are least confident in teaching, along with other topics in which teachers lack confidence, thus providing guidance to those responsible for teachers' initial training and subject-specific CPD providers.

It is widely recognised that chemistry is a challenging subject for those who study it. The abstract nature of chemistry concepts can lead to misunderstandings among students, which hamper their progress (Zoller, 1990). As these concepts are crucial in developing a meaningful understanding of chemistry (Taber, 2002), it is imperative that they are well understood by students. If they are not, this can lead to the development of misconceptions.

Similarly, it is crucial that science teachers understand the subject matter that they teach (Abell 2007; Van Driel, Berry and Meirink, 2014) to ensure that their students can comprehend it (McConnell *et al.*, 2013). Coe *et al.* (2014) cite six components necessary for great teaching, that is, '*that which leads to improved student achievement using outcomes that matter to their future success*'. The first component is *'[pedagogical] content knowledge'* (PCK), as there is robust evidence to suggest that this has an impact on student outcomes (Hill, Rowan and Ball, 2005; Sadler *et al.*, 2013). The RSC also argue that good subject matter knowledge (SMK) is essential in good teaching:

> *The best teachers are those who have specialist subject knowledge and a real passion and enthusiasm for the subject they teach … the Royal Society of Chemistry believes that young people deserve to be taught the sciences by subject specialists.* (RSC, 2004, quoted in Kind, 2009: 169)

This article discusses the key findings from a teacher survey, with a particular focus on confidence levels in different topic areas. It is intended that this article will provide guidance to those responsible for teachers' initial training and subject-specific CPD providers.

Methodology

The survey questions were grouped into five main sections:

- Demographic information
- Impact of teacher training
- Subject matter knowledge for chemistry
- The A-level curriculum and beyond
- What makes a good teacher?

For the data obtained to be meaningful and easier to interpret, three types of question were used in the survey. Simple yes/no questions and Likert scales were used for participants to share opinions and make the data quantifiable. In addition, open-response questions were included, many being coupled with yes/no or Likert scale questions to give participants the opportunity to provide explanations. The survey was initially trialled with four A-level teachers, with amendments made to ensure that the desired data and level of response would be received. Ethical approval was obtained via the university's ERGO system, with BERA guidelines being followed.

The survey was publicised via email to an outreach mailing list (207 teachers), via email to subscribers to *Education in Chemistry*, and publicly via *Twitter*, resulting in 51 responses. Completion times were typically between 45 minutes and one hour. All participants who responded to the online survey were self-selecting, and therefore the dataset obtained represents a convenience sample. Responses to closed-response questions were quantified and tabulated or graphed. Responses to the open-response questions of the survey were

analysed by content analysis using *NVivo* (Versions 11 and 12) software.

Analysis of teachers' responses to questions and prompts in the 'SMK for chemistry' section of the survey are discussed below.

Results and discussion

The undergraduate degree and confidence in chemistry teaching

To explore the perceived influence of the undergraduate degree on SMK, participants were required to respond to statements 1a and 1b using a five-point Likert-type scale:

> *My undergraduate degree provided me with enough chemistry subject matter knowledge to feel confident teaching GCSE chemistry.* (1a)
>
> *My undergraduate degree provided me with enough chemistry subject matter knowledge to feel confident teaching A-level chemistry.* (1b)

After providing responses, participants were prompted to briefly explain their choices (Figure 1).

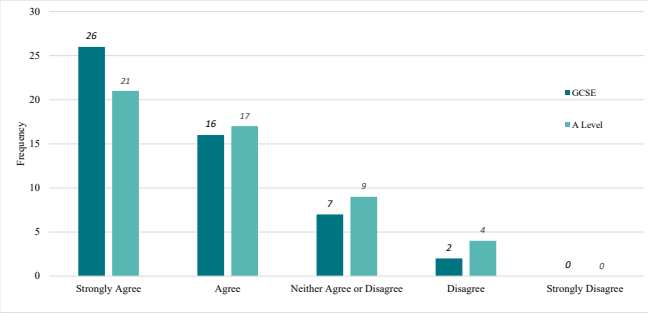

Figure 1 Teacher responses to statements 1a and 1b

Responses were positive overall, with 82.4% (n = 42) strongly agreeing or agreeing that their degree provided them with enough chemistry SMK to feel confident teaching at GCSE level, and 74.5% of respondents (n = 38) strongly agreeing or agreeing regarding teaching at A-level. The high level of agreement reveals a belief that the completion of a degree has provided enough SMK to give confidence in teaching. Some teachers reported views that assert the value of a chemistry degree to a chemistry teacher, which are pertinent given the increased preponderance of non-specialist teachers:

> *I am able to stretch those from GCSE to A-level and then beyond, [based on] my own education.*

Some teachers noted gaps in their knowledge and understanding despite holding chemistry degrees, emphasising the importance of SMK development during ITT and beyond (Kind, 2014):

> *My major problem was that I never fully understood the subject. So when I went to university again these gaps in my knowledge were never filled in (from both GCSE and A-level). [It] took until I started teaching to realise this.*
>
> *I've had some issues with subject knowledge when teaching A-level. Some students have questioned me and I have had quite a weak understanding and only surface learned some topics.*

One teacher acknowledged the limitations of a chemistry degree in developing teacher knowledge:

> *I think it's very important to understand where student misconceptions appear from and how to challenge them with care. Degree programmes don't do this; teacher training should do this but from my experience they definitely didn't.*

An important element of a teacher's awareness is what their students know and don't know, to provide a meaningful educational experience (Ausubel, 1968). This awareness should include an understanding of misconceptions, so that a teacher can easily identify and challenge these misconceptions at source. This comment supports the need for specific training on misconceptions and implies the contribution of experience to a teacher's PCK (Grossman, 1990).

The extent of a teacher's SMK

Participants responded to statement 1c below using a five-point Likert-type scale, with their responses being illustrated in Figure 2:

> *In relation to subject matter knowledge, a teacher of A-level chemistry should be an expert in their field.* (1c)

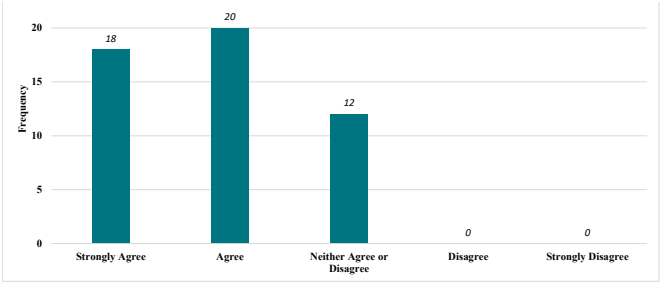

Figure 2 Teacher responses to statement 1c

The overall response to this item was positive, with 76.0% of respondents (n = 38) strongly agreeing or agreeing that an A-level chemistry teacher should be an expert in their field. It is not surprising to see that no participant disagreed or strongly disagreed with this statement, as many teachers may perceive themselves as experts. Among those who strongly agreed or agreed with statement 1c, the most prominent theme was the requirement for knowledge beyond the specification (n = 14). Representative quotes include:

In order to gain pupil confidence you need to know your stuff … how much of an expert you need to be may be up for discussion but you need knowledge beyond the A-level spec.

You need to have a grasp of what lies beyond A-level, even if it is a hazy fuzz from years ago. It helps frame the teaching you do post 16 and pre 18.

Confidence was also observed to be a prominent theme in the responses of those who agreed with statement 1c. These participants justified their agreement with the statement through arguing that to communicate content effectively, a teacher must be confident in their SMK:

This goes without saying. If you are not an expert it will be obvious to students and you will lose their confidence quickly. You need to be an expert to clearly deliver the content.

It is a challenging A-level. A teacher who is not secure in their knowledge cannot develop confident learners.

It was acknowledged that teachers may not begin their careers as experts, highlighting the importance of strong SMK in making links between different concepts, something that is integral to strong PCK (Hashweh, 1987). This also aligns with Childs and McNicholl's (2007) assertion that a teacher cannot plan effective lessons until they have mastered the content themselves:

Only now I have taught the organic topics a few times do I feel confident – this is perhaps becoming an expert in those topics and this allows me to be a much better teacher, make curricula links as well as explaining clearly why things happen.

Similarly, a number of responses (n = 9) related to teachers having an awareness of their students' learning and interest in chemistry:

All teachers should be experts in their field, otherwise it devalues teaching and education. Pupils have the right to be taught and inspired be someone who has a deep interest and love for their subject.

Students will find it hard to be inspired by someone who they do not consider an expert.

Some participants agreed with statement 1c with the caveat that it depends on the definition of 'expert'. Eight of 12 participants who selected the 'neither agree or disagree' option cited this in their reasoning, with some suggesting that a high level of expertise can be detrimental to teaching ('*the curse of knowledge*' – Camerer, Loewenstein and Weber, 1989):

Depends what is meant by expert. I have been taught by people who are 'experts' i.e. at the cutting edge of research who have not been able to explain things very well.

These comments imply that there is a link between having a high level of SMK and a low level of PCK (in this case how to convey fundamental ideas in topics of great expertise), similar to the findings of Harris and Sass (2007).

Two teachers referred to the fact that you don't need to be an expert from the beginning of your teaching career, and that experience is essential in developing expertise:

I don't think it's realistic to expect a teacher to be an expert in the specification content of a subject from the word go, but it's something that they should be working towards over the course of the first few years of their teaching career.

Other participants emphasised that higher levels of knowledge allow for discussion beyond the specification:

You should always be ready to go beyond what is needed. A student might ask a question that needs a higher level of understanding. For example, a Y7 once asked how the hi-vis stripes on his cycle helmet worked; some 6th form students guessed that there was a link between Gibbs free energy and equilibrium. It was good to be able to explain these … and grab their interest.

Teacher workload was cited as a problem by one respondent, emphasizing the importance of developing SMK during training and in the early stages of a career in teaching:

Not having a suitable subject qualification to teach chemistry makes workload much higher … teachers rarely have the time in their day to day work to top up their subject knowledge.

Participants were asked if they were confident in their SMK before they started teaching, and were then asked if their confidence changed once they started teaching (Table 1).

Table 1 Teacher ratings of confidence in their SMK before and after starting teaching

Before teaching	After teaching	No. of respondents
Not confident	No change	1 (2.0%)
Not confident	Confidence increased	9 (17.6%)
Not confident	Confidence decreased	1 (2.0%)
Confident	No change	18 (35.3%)
Confident	Confidence increased	17 (33.3%)
Confident	Confidence decreased	5 (9.8%)

Responses from participants who reported increased confidence after teaching include:

Confidence improved the more I taught and reflected.

Once teaching my confidence improved as I gained curriculum knowledge.

Responses from participants who reported decreased confidence after teaching include:

I realised how much I had forgotten (or possibly never knew).

The gaps in my knowledge … were now exposed.

Two salient quotes highlighted the need for the teacher to understand the conceptions that students bring with them to the lesson – and, of course, those of the teachers themselves:

Realised that to teach I had to get below the level of the students to make sense of what they were trying to do with their knowledge.

Your understanding can be excellent, but without a thorough understanding of how students can misunderstand your subject then you will find it difficult to teach them.

Methods of SMK development

Participants were asked whether chemistry SMK development was a compulsory part of their ITT, with a small majority (53%) indicating that it wasn't. Quotes from respondents who did experience SMK development during ITT indicated that coverage was patchy. 73% of respondents indicated agreement or strong agreement with the statement that '*Training providers should offer more SMK development support during teacher training*'.

One participant explicitly stated that the SMK development in their ITT course was '*very poor*', due to a focus primarily on GCSE level chemistry content but no A-level content. As has been previously noted, it can be said that a specialist degree is not necessarily an indicator of strong SMK (Kind, 2014), and it can be argued that ITT providers should therefore work more with pre-service teachers on enhancing their SMK.

When participants were asked if they undertook self-directed SMK development during training, only 61% reported that they did. In a majority of cases, this involved the use of textbooks, while use of past papers was another commonly cited approach. A number of respondents emphasized the importance of working with non-specialist teachers to develop their SMK:

I find new colleagues coming into teaching with less specific degree courses (chemistry teaching with a forensics degree or biochemistry degree) who find the more technical and mathematical topics a challenge to teach.

People on my course without a strong chemical background really needed more subject help.

Other respondents cited the challenge of squeezing SMK development into already packed ITT programmes:

A very tricky one for providers – there is a huge range of other parts of ITT that need to be covered in a very short time.

It is up to an individual as to what they want/need to do to prepare. There are enough resources out there for someone to use if they need to develop their SMK. Teacher training should be focused around skills needed as a teacher.

To investigate how continual SMK support can be provided for teachers following Qualified Teacher Status (QTS), and to provide insight into the methods and resources that could be used, survey participants were invited to respond to question 1d:

In your opinion, what can teacher training and CPD providers do in order to support A-level chemistry teachers with their subject matter knowledge development after they have qualified? (1d)

Some illustrative responses to this question are given below:

Provide SKE for established teachers in well-known trickier topics, e.g. electrochemistry and kinetics.

*When new specifications come out, have CPD courses **before** they have to teach the new spec, bridging the gap between old and new specs.*

This is essential for topics which are new to the syllabus in particular (e.g. TOF mass [spectrometry]).

Nine participants commented on the importance of communication with other teachers, and how it is important for CPD and other sessions to be available in school settings:

Providing resources that can be adapted to in-school/school group settings so more expert teachers can deliver/support other teachers.

It is difficult because teachers can be as bad as students in asking for assistance if they don't know something. More informal meetings between newly trained teachers and experienced teachers of the same specifications may help.

Some of these participants noted that local chemistry teacher networks are valuable in developing teaching skills, reporting that having

opportunities to share good practice with others has been beneficial in developing SMK and PCK. Five participants reported that having access to online events would be an effective way of providing SMK enhancement.

Identification of high and low confidence topics

Participants rated their confidence in their ability to teach ten A-level chemistry topic areas, ranking them from 1 (highest confidence) to 10 (lowest confidence). The ten topic areas were chosen based on a review of the content of the UK's A-level chemistry specifications (Read and Barnes, 2015). The responses to this question are detailed in Figure 3.

Atomic structure and molar calculations is the topic that participants are most confident in teaching:

> *Underlying concepts which get studied often, so I have lots of practice with it.*
>
> *A fundamental topic that you must know well in order to explain and teach and absolutely necessary to the understanding of the rest of chemistry.*

Nine of the survey participants commented that organic chemistry was a topic of high confidence because they enjoy its problem-solving nature, which is notable as this is known to cause difficulties for learners:

> *I like structures and mechanisms. There is an element of filling the gaps if you don't know the exact reaction.*
>
> *It's possible to see the big picture and get [the students] to understand the key principles that they can then apply.*

Twelve participants ranked analytical techniques among their three least confident topics. A lack of experience teaching the topic was the most-cited explanation. Two participants reported that the level of study was a cause of low confidence, but for opposing reasons. One participant remarked that the level that it is studied at during the undergraduate degree is '*not helpful*' for A-level teaching, in that it is too in-depth, while the other noted that there is a '*lack of familiarity from GCSE*'. One participant mentioned that there is a '*lack of good practical [sessions]*' to support learning of the topic, making it harder to provide relevance and context. Those with high confidence discussed its relevance to their previous jobs.

Very few survey participants ranked the topics of chemical equilibrium and kinetics in their top four. For equilibrium, participants remarked that they did not have much experience of this topic and found it difficult to simplify. For the kinetics topic, nine participants remarked that the mathematics behind understanding the topic were too difficult:

> *Some of the mathematical applications solving Arrhenius equations means that it can be difficult to help pupils pinpoint errors.*
>
> *Purely Arrhenius equations and rearranging as I only have GCSE level maths.*

The explicit reference to the Arrhenius equation in these comments indicates a need for SMK support when A-level specifications are changed.

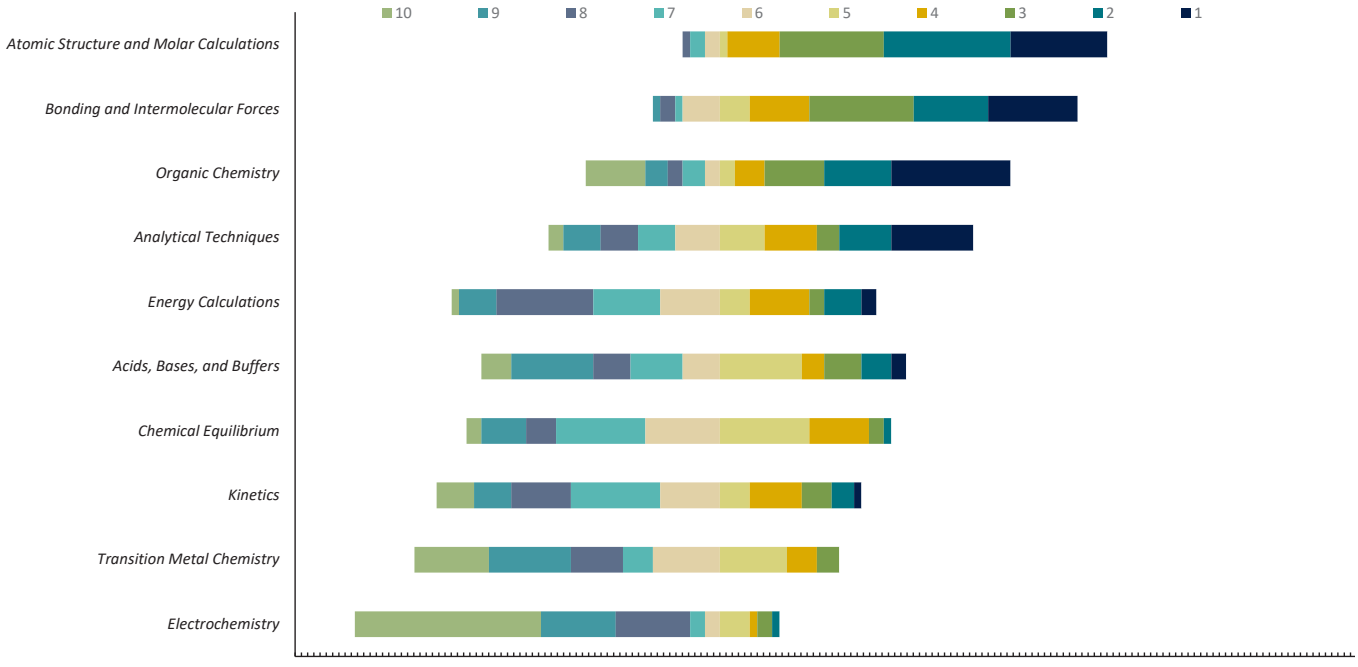

Figure 3 Teacher ratings (n = 57) of their confidence in teaching different topics, where 1 = most confident and 10 = least confident

The finding that both transition metal chemistry and electrochemistry appear in the bottom two positions is significant in highlighting a general lack of confidence in these topics across A-level chemistry teachers of different experience levels and backgrounds:

> *[Transition metal chemistry] was not part of my degree /PGCE course.*
>
> *I did not do this at A-level.*
>
> *Not studied in detail at degree.*

Six participants cited their lack of experience teaching the topic as a reason for their low confidence, as observed elsewhere. Their remarks are in agreement with the assertion that a teacher's PCK develops with greater classroom experience (Grossman, 1990; Magnusson, Krajcik and Borko, 1999; Van Driel, Beijaard and Verloop, 2001). The main reason given for lacking confidence in transition metal chemistry was the amount of rote memorisation required:

> *Principally because the level of understanding doesn't really have a lot of explanation behind it. So it feels more along the lines of this is what happens and this is how you apply it. Not much why.*

For electrochemistry, the most common reason given for lacking confidence was that teachers found it difficult when they studied it themselves ($n = 17$):

> *I did not understand electrochemistry during my degree.*
>
> *Really disliked it at A-level. Never truly understood it.*
>
> *Negative feelings relating to ability at university to answer questions.*

Three participants attributed their unease with electrochemistry to the way it is covered on A-level specifications, with one participant stating that A-level '*doesn't give satisfactory explanations, so students often ask questions I find difficult to answer*'.

Further to these comments, seven participants reported that electrochemistry can be a confusing topic for students, with a further six remarking that terminology can lead to further confusion and misconception development:

> *I find that pupils tend to get themselves in a muddle over different rules.*
>
> *Brings together equilibrium with a number scale that runs from negative to positive, always seems to cause confusion.*

One survey participant commented on the link between electrochemistry and physics and how this can cause confusion:

> *There can be conflict with the physics department on precise definitions and my weaker background in electrochemistry means I am less confident with my explanations.*

This comment infers that the teaching of fundamental concepts in physics (e.g. the direction of current flow), at both GCSE and A-level, may not fit with how electrochemistry is taught. For those who are required to teach both physics and chemistry, this could be problematic. As detailed by Garnett, Garnett and Treagust (1990), the compartmentalisation of science subjects is a potential cause of misconceptions in electrochemistry, in addition to inadequate prerequisite knowledge. Four further participants reported a lack of interest in electrochemistry as the reason they felt less confident in their ability to teach it.

Conclusions and future work

The conclusions are presented with the caveat that the sample size is small, meaning that the findings may not necessarily be extrapolated onto the wider population of chemistry teachers. The data nonetheless provide valuable insights for ITT and CPD providers.

The identification of transition metal chemistry and electrochemistry as near-universal topics of low confidence is an important outcome of this project. In future, it is recommended that resources and CPD courses should be developed in order to enhance A-level chemistry teachers' SMK in these areas. Further to this, investigations on the relationship between the level of a teacher's SMK and their confidence in it could also be undertaken, in order to ascertain further whether improving teacher confidence can have a positive impact on student learning. Participating teachers, including both novice and experienced teachers, felt that ITT providers should offer more SMK development support during ITT. Although the nature of ITT involves the coverage of a large amount of information and pedagogical theory, there is a clear desire for trainees to have resources available to them. Participants identified that more focus should be given to topics that are difficult to teach. Given that these topics have been identified in this study, work can be undertaken in future to develop resources to facilitate this focus. Participants also requested to approach topics from different perspectives, and focus on common misconceptions,

feedback and action plans, and putting concepts in the context of practical work. These factors should be considered in the development and evaluation of any resources created in future.

Finally, numerous issues discussed by participants in this study related to issues with specialist language and terminology, an issue that has been identified in numerous studies (Garnett *et al.*, 1990; Taber, 2000; Taber, 2002). Further investigation into the aspects of language and terminology that cause difficulty for students and teachers should be considered, in addition to inquiry into the methods that can be used to ameliorate teachers' concerns regarding terminology. If such methods can be identified, it would be beneficial for resources for teachers of all experience levels to be developed that can attempt to tackle these problems.

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