The Nature of the Chemical Concept
Re-constructing Chemical Knowledge in Teaching and Learning

Keith S. Taber
The Nature of the Chemical Concept
Re-constructing Chemical Knowledge in Teaching and Learning
Advances in Chemistry Education Series

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The Nature of the Chemical Concept
Re-constructing Chemical Knowledge in Teaching and Learning

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Preface

This is a book that is partially about cognition, partly about education, and partly about chemistry. Part of my motivation in writing this book was to do for the chemical concept what Linus Pauling did for the chemical bond in writing his ‘The Nature of the Chemical Bond’: that is to provide some kind of coherent treatment of a topic that appears imprecise and confused in much of the literature. Concepts are central in teaching and learning, and I felt an attempt to address the topic for those who are working in chemistry education was sorely needed. Indeed, I considered that an authoritative account could support teaching – and that if the present attempt is judged inadequate in that respect, then this might at least provoke those who recognise its faults to attempt to do better.

In writing the book I have been very aware of my own limitations for the job. I appreciate that what I was writing was, in places, of its nature philosophy, and, in other places, I was attempting to offer insights from the history of chemistry. Yet I am not, and have no training as, either a philosopher of, nor as a historian of, science. Whilst I can certainly claim to be a chemist, I am not a research chemist – my research has only ever been in education.

So, if I have qualifications for writing this book, they must be found elsewhere. I have had, since my school days, a strong interest in science and how science comes to knowledge, and also in learning – and so how learners may come to knowledge. I have taught in secondary schools (mostly chemistry and physics), further education (mostly chemistry and physics, but also some science studies and research methods), and in university (mostly in science teacher preparation, and educational research methods). So over almost forty years I have spent a lot of time trying to communicate scientific concepts, and notions of how we can come to knowledge, to students.
So, this book is borne out of my teaching experiences as well as my research interests.

It seems (from my own experience) authors normally plan a book, and make a formal proposal to a publisher, at a point where they think they have a clear vision of what they want to achieve and how they will go about it. The actual writing process is often extended, and is where much of the detailed thinking is done. This often reveals that the vision needs a lot more work than the tidy proposal might have suggested. It may seem that once an author has the plan for a book it is just a matter of doing the writing, but that would both be naïve, and indeed probably make writing a book somewhat tedious. So, from the author’s perspective, a good book proposal should reflect enough thinking to give confidence that the plan for the book is viable, but not so much that the writing seems a mechanical process of carrying out the plan.

Sometimes, during the writing, the author may need to revisit (or even reimagine) what the core of the book is – or was meant to be. During the writing process for this volume I asked myself why anyone should read this book with its ‘enthusiastic amateur’ treatments of topics from the nature of chemistry and the history of the subject, when there are plenty of scholarly accounts of such matters written by genuine experts in those fields. The answer is that although arguments in the book draw on a number of fields, its origin is in teaching chemistry, and the experience of teaching chemical concepts – and then of undertaking research into how students understood those concepts. In that sense, this book develops a theme from an earlier book (Taber, 2013) that although teaching is a professional activity, it often relies on what are little more than folk notions of key ideas (‘concept’, ‘learning’, ‘understanding’, ‘knowing’, etc.)

Teaching chemical concepts is a challenge. In part it is a challenge because once one has acquired a decent conceptual knowledge of the subject it becomes difficult to put oneself back in the position of a novice learner; in part it is a challenge because chemical concepts are abstract and often nuanced – and often highly inter-related (such that you never really understand some concepts until you also understand a number of others); in part it is a challenge because teachers of chemistry at all levels – through no fault of their own, it is in the nature of developing expertise – tend to operate with almost intuitive notions of the nature of the concepts they teach, and of what understanding those concepts actually means.

So, although this book is envisaged as a scholarly account suitable for graduate students and academics, I have tried to write in a way that addresses anyone who teaches chemistry, or works with students learning chemistry, as well as for those undertaking research into teaching and learning. It is a book that problematises the notion of the concept in chemistry, and sets out to show why teaching and learning chemical concepts can be so challenging. The book then offers an analysis of the background to much of what chemistry teachers and lecturers are doing in their classroom work. It is a book that comes from a privileged position that most
chemistry teachers do not share: despite my very dubious qualifications in some of the key disciplines I draw upon, I am lucky to have had a career teaching across natural science and social science (education) that has given me opportunities to read a little across a range of fields and so consider how diverse perspectives might inform thinking about teaching chemistry. I have also benefitted from the generous participation of many students who were kind enough to share with me their own understandings of the concepts they have been taught. This offers a diversity of perspectives and experiences to make the present book viable (Taber, 2014).

I hope, then, that this book will be read not only by researchers and graduate students, but also by those teaching chemistry, at whatever level, and that it will resonate with teachers’ experiences of the challenges they face in their classroom work. I would like to think it offers useful insights to help them better appreciate the nature and sources of these challenges, and so help teachers better support the learners they share our chemical concepts with.

Keith S. Taber

References


A number of key terms are discussed in this volume – being introduced and explained or developed at different points in the text. This glossary is provided for ready reference for the reader dipping into the book or requiring a quick reminder of how a term is being used.

**Accredited concept**  An accredited concept is a learner’s personal concept (of some chemical notion, such as ‘element’ or ‘acid’) that has been judged as being sufficiently aligned with the target knowledge set out in a particular curriculum.

**Alternative conception**  An alternative conception is a way of conceptualising something that is judged to be inconsistent with the accepted (‘canonical’) way of thinking about that particular topic or phenomenon.

**Authoritative concepts**  This term is used in the book to refer to those personal concepts that experts in a field have developed that are sufficiently aligned with those of their peers (i.e., other experts) such that they are widely judged canonical, and so facilitate ready communication within the community of experts.

**Canonical concepts**  A canonical concept is taken as the standard conceptualisation within a field. Canonical chemical concepts may be considered to have the authority of being the established ways of making sense of the discipline of chemistry.

**Conception**  A conception is a way of conceptualising some aspect of the world. A specific conception may be one aspect of someone personal concept (e.g., ‘the covalent bond is a shared pair of electrons’ may be a conception that is part of, but does not exhaust, someone’s {covalent bond} concept).
**Conceptual content**  This term conceptual content is used for the ‘content’ of a particular concept in the sense of the full set of meanings and associations it has – which could include such matters as examples of the concept, understandings of applications of the concept, etcetera.

**Conceptual inductive effect**  As concepts are embedded in conceptual networks, they are influenced by the associations of other concepts that they are directly linked to – or to put this another way, they are implicitly influenced by those concepts that they are indirectly linked to through other concepts.

**Congenst**  A hypothetical feature of a person’s neural structure, representing aspects of previous experience, which, when activated, supports thinking characteristic of applying a concept: a concept-generating structure in someone’s brain.

**Creditable concept**  A learner has a creditable concept when their personal versions of some chemical concept is sufficiently credit-worthy, at the level they are studying, to be evaluated as an accredited concept (if and when such an evaluation takes place).

**Curricular models**  It is seldom, if ever, possible to teach scientific concepts in their full sophistication and complexity including all known examples, properties, associations, etcetera; so, concepts are in effect modelled (e.g., simplified, generalised, exemplified by prototypes) in the way they are represented in curriculum.

**Historical concepts**  These are concepts that once had wide currency in chemistry – and so might have once been considered canonical – but that are no longer part of the canon of chemical thinking.

**Knowledge**  A person’s knowledge is understood here in the inclusive sense of ideas believed or being entertained as plausible (regardless of their objective correctness).

**Mooted concepts**  Not all scientific concepts become widely adopted and so can be considered canonical. The term mooted concepts is used to distinguish those scientific concepts that are currently under consideration, having been proposed in current scientific publications that have not yet, and may never, become widely used in the scientific discipline (be that chemistry generally, or a more specific research field).

**Optimum level of simplification**  A teaching presentation should simplify canonical concepts sufficiently for the material to be meaningful, and understood as intended, by the students; without being oversimplified so that it becomes an inauthentic representation of the canonical concept and/or a poor basis for further progression in learning.

**Personal knowledge**  Personal knowledge refers to the knowledge of an individual, and is therefore somewhat idiosyncratic.

**Public knowledge**  Public knowledge refers to what is widely taken for knowledge in society: in a science such as chemistry this is often understood in terms of what has been reported in the research literature – although it may be difficult to determine precisely what counts as public knowledge.
Scientific concepts  Unlike everyday concepts that develop through informal cultural processes, scientific concepts are those that are mooted formally as part of scientific practice – understood here as an iterative process that seeks to conceptualise empirical experience theoretically, and test such theoretical inventions empirically, and so on.

Tacit knowledge  Tacit knowledge refers to knowledge that a person would seem to have (as they appear to demonstrate behaviour informed by that knowledge) even though they are not consciously aware of what it is they know, and cannot readily deliberate on it. Tacit knowledge is related to the idea of intuition – an ability to make judgements without conscious reasoning.

Target knowledge  The knowledge set out for a particular group of students to learn, as in a formal curriculum. For example, target knowledge about chemical reactions will vary between, say, middle school pupils; school leavers; and final-year undergraduates.

Typographical Conventions

Two particular typographical conventions are used in the text. One is to use curly brackets to put concept names in parentheses when referring to a concept rather than what the concept refers to: so, for example, to distinguish references to the concept \{metals\} from references to actual metals. Sometimes subscripted suffixes are used to distinguish distinct versions of concepts – such as the \{acid_{Arrhenius}\} concept and the \{acid_{Lewis}\} concept. The other convention is to denote the inverse of some group or category, so, for example, to use acid to denote anything that is not considered to be acid, and therefore to denote the concept of all those things that are not acid as \{acid\}. 
Acknowledgements

A text, even a single authored text, never has a single author.

Scholars are supposed to be careful about assigning credit, and to acknowledge all those who have informed their thinking. Yet learning is an incremental, interpretive, iterative, and, often, insidious, process, and so we are only ever vaguely aware of the sources informing many of our ‘own’ ideas. In a sense, then, any author is actually an inadvertent editor of a multitude of hidden, indirect, contributors to a work. I would like to acknowledge the role of this invisible college in the current work – all those who have influenced my own thinking through representing their own ideas in the public domain. I have cited some key influences in the text, but wish to acknowledge that my thoughts are inevitably the outcome of a complex blending of all the information I have made sense of during a lifetime of interpreting what I have heard and seen and read. The many misinterpretations are, of course, all the author’s own work.

So, I readily acknowledge that this book is, in part, the product of my upbringing, my schooling, and all my other educative experiences over many years. In particular, I thank my parents for creating a supportive and loving home environment that provided the grounding for all that followed. I also thank my own teachers, and professional colleagues, and all those whose writing influenced my thinking (even when I have no explicit memory of that influence, or even the texts concerned, now). A teacher’s thinking is developed in responding to the unexpected questions of those we teach. My own thinking has been developed in collaboration with those I have taught at school, college, or university level, as well as those students (whether I taught them, or not) who generously gave me some of their precious time to be interviewed about their understanding of concepts.
Acknowledgements

I would also like to thank the Royal Society of Chemistry for recognising the value of a book series focused on chemistry education as a scholarly field, and my editor there, Michelle Carey, for her patience and support.
To Philippa
always in my memory
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INTRODUCTION
CHAPTER 1

The Challenge of Teaching and Learning Chemical Concepts

Chemistry as a subject is conceptual. Students learning chemistry at school level, or in colleges and universities, are introduced to, and asked to master, a wide array of concepts. So, students at different levels are taught about acids, elements, oxidising agents, covalent bonds, d-level splitting, chemical shift, and so on. Each of these, and many other, foci of study can be considered concepts (the nature of concepts is discussed in Chapter 2). Concepts are central to understanding chemistry, and the understanding of chemical concepts is therefore a core concern in chemical education.

Chemistry is a science, and arguably one thing that characterises science is the interplay between empirical experience and theory. Chemistry is often said to be a ‘practical’ subject, but what makes such practical work a scientific activity is the way it is informed by, and feeds back into, the theoretical frameworks of the subject (this is explored further in Chapter 5). Those theoretical frameworks are populated and supported by the wide range of concepts chemists have developed to make sense of what has been seen (and heard, smelt, felt, and – more so in former times – sometimes tasted) in the laboratory. Reflecting this, an authentic chemistry education is rich with concepts that are set out in the curriculum, presented in textbooks, and taught in the laboratory and classroom or lecture hall.

Yet learning chemical concepts is not straightforward. Students – at all levels – often do not understand; or only partially understand; or indeed misunderstand; key concepts they meet in their studies of chemistry. Students in these situations are sometimes well aware they are confused or do not understand what is being taught: but that is by no means always the case. Indeed, it is not at all unusual for students to only partially understand, or indeed misunderstand, concepts that they think they do understand.
When students present with conceptions that are inconsistent with the target knowledge being taught, their ideas are often labelled using terms such as misconceptions, alternative conceptions or alternative frameworks. Such terms are justified because often (although not always) students' alternative ideas in chemistry are well established and strongly committed to (see Chapter 14). So, even when the teacher becomes aware that there is an issue, modifying student thinking may not be straightforward (see, in particular, Chapter 15). This is one of the core issues in chemistry education (Taber, 2002).

This is clearly not the only issue of importance in modern chemistry education. Another would be developing the most relevant curriculum for particular student groups (Eilks and Hofstein, 2015). This may be ‘most relevant’ in terms of preparation for further study, for professional life in chemistry, or for wider citizenship. This may also be relevance in terms of what students themselves feel is relevant to their lives, interests, and concerns. These two areas of concern may overlap, but need not.

What is most relevant for future chemistry PhD students may not be so relevant for most school students required to study the subject, or even for most undergraduates taking a general chemistry course to meet matriculation requirements (as happens in some national contexts). This is a very important issue: education uses valuable resources, so investment in education should be carefully targeted. Students, especially those in compulsory education, have a right to expect decisions influencing their lives (such as the curriculum they are expected to study) to reflect their best interests (Taber and Riga, 2016). Student motivation may be strongly influenced by learners’ perceptions of course relevance, and this in turn influences course completion, achievement, and decisions about progression to further courses.

Perhaps future curriculum reviews and developments might reduce the conceptual load in high-school chemistry, or substitute some of the concepts presently included with new concepts perceived more relevant to the student group. Updating courses in further (post-compulsory) and higher education will over time lead to more recently developed chemical concepts replacing some of the traditional concepts as they come to be seen to be less important in chemical research and practice today. Scientific concepts themselves evolve (see Chapters 5 and 6), so, for example, the concept \{acid\} today is somewhat different from what was nominally the ‘same’ concept when it first appeared in a chemistry curriculum. (The use of parentheses (i.e., \{\}) to mark concept labels is introduced in Chapter 2.)

So, the actual concepts met in chemistry courses will change. However, given the nature of chemistry as a subject, teaching chemistry will always involve teaching students a good deal of conceptual material, and much of that will remain challenging. That is, challenging for students to learn, and so challenging for teachers and lecturers to effectively teach. Moreover, it seems very unlikely that some of the core concepts of chemistry today, concepts known to often be found challenging, will ever come to be judged
superfluous or anachronistic in chemistry courses. Certainly, concepts identified as core when I was a school-age student (Fensham, 1975), are still core today. For example, a serious study of chemistry as a science is likely to always need students to learn about elements and compounds; atoms and molecules; and periodicity.

A premise of this book, then, is that the very nature of the subject of chemistry means that understanding its conceptual content is challenging, and so many students will face learning difficulties with much of the material – and that, consequently, teachers will find that teaching these concepts effectively is not straightforward. If that seems pessimistic, then it is hopefully balanced by two other premises underpinning the book. One is the optimistic view that learning can be supported, and teaching can be informed, by an understanding of the nature of this challenge. Informing teachers at all levels about the nature of conceptual learning in chemistry, and why it often seems to go wrong, can allow them to develop more effective teaching strategies. A second optimistic assumption is that whilst, certainly, more research is needed (see Chapter 16), there is already a good deal of research that can help teachers understand in general terms the problems and potential solutions when teaching chemical ideas.

Some of this work derives from research in psychology, or in what are sometimes referred to as the learning sciences, and some originates in educational studies exploring general aspects of teaching and learning. Much of that work is generic in nature, and potentially as applicable to learning in, say, mathematics, or history, as in chemistry – but it nonetheless offers useful theoretical frameworks and perspectives for understanding the general nature of learning processes.

Complementing this, is research that is more specifically relevant to teaching chemistry in particular. Science education is now a very well-established field with a wide range of periodicals (including a number of highly regarded, well-established, research journals), and within science education there has been a vast amount of work exploring students’ learning of science concepts, and the development of student thinking in response to teaching. Some of this work is specifically based on teaching and learning of chemical concepts.

In recent years, chemistry education research has become better established as a field in its own right, with its own journals, research groups, conferences, and the like. Again, one of the key areas of research within chemistry education has explored student thinking and learning in particular topic areas, and there has been much attention to the nature of student conceptions and the challenges of learning canonical chemical concepts (Taber, 2018a).

The present book is therefore an attempt to offer an account of the nature of chemical concepts, and the learning of those concepts, based on the current state of knowledge drawn from within and beyond chemistry education. The purpose of the book is two-fold. One goal relates to the area of research itself. Although there is a good deal of relevant research, we
certainly do not know all that it would be useful to know about the teaching and learning of chemical concepts. This book also acts as a snap-shot of the current state of our knowledge in this important area, and by reviewing the current state of the field, the book offers indications of fruitful directions for further research. Hopefully, such an account will support those setting out on research, as well as those planning teacher education and development programmes. I hope also to offer a readable account that will be informative for all teachers of chemistry, to support teachers in developing greater understanding of the nature of the challenge of teaching chemistry concepts to students – and to therefore inform more effective teaching practice.

1.1 Research is Underpinned by Theory

It was suggested above that scientific research in chemistry depends upon interplay between theory and practical enquiry. This is so in any scientific field. Those of us who work in science education and/or chemistry education consider that our research should be, or at least aspire to be, scientific in nature. Educational research is essentially social science, but still science. The distinction is important, as clearly the assumptions and methods that apply in – say – enquiry into synthetic routes towards biologically active natural products, are not directly transferrable to enquiry into teaching and learning processes in a school classroom or an undergraduate chemistry laboratory.

However, there are expectations that would apply to those undertaking research in any field that we wish to consider as scientific. We expect chemistry research to be undertaken by those who have been prepared for chemical enquiry by induction into both the theoretical background and the experimental procedures and techniques needed to contribute to the particular specialist field. Someone who did not know their chemistry and had not been trained up in how to work in the laboratory is unlikely to produce empirical research that meets the requirements of peer review. For that matter, someone whose background and experience was (for example) in working with gases on vacuum lines would not be expected to suddenly switch to producing publishable work on cell biochemistry without a further period of specialist preparation.

The same kinds of expectations should apply just as much in chemistry education. Journals publishing research that makes recommendations for how teachers should go about their professional work practices need to subject that work to rigorous evaluation: to ensure the work is based on appropriate theoretical perspectives supported by relevant research literature, and that it has been carried out using a suitable research design that employs appropriate data collection and analysis techniques (Eybe and Schmidt, 2001; Taber, 2012b). This raises the question of the extent to which chemistry education, or science education more widely, might be considered research fields that deserve to be seen as scientific.
These fields certainly exist as well-established foci of scholarly and research activity (Gilbert, 1995; Fensham, 2004; Taber, 2012a), with periodicals, conferences, networks, book series, and the like. The more important journals certainly reject most submissions (which is one crude indicator of peer review rigour). There are, however, some distinctions between chemistry education as a field and most established areas of chemistry. Clearly methodologies used in educational research are often quite different from in the natural sciences, as is appropriate given the different foci of interest (Taber, 2016). Of more significance is the diversity of theoretical perspectives and methodological approaches that are employed within the field of chemistry education (Taber, 2014). Thomas Kuhn (1970) suggested that within a mature science there tend to be accepted norms relating to a range of considerations (such as terminology, key concepts, techniques, reporting formats and the like), whereas within chemistry education it is not unusual to see diverse terminology, alternative perspectives, and different methodologies applied to particular foci of interest.

In part, this could be argued to reflect chemistry education as a less mature field where a common ‘disciplinary matrix’ (Kuhn, 1974/1977) is still to be established, and where induction into the field is through a less formal training regime. Increasingly studies submitted for publication in chemistry education journals are led by scholars with PhDs in chemistry education – but many researchers in the field are primarily trained as chemists, or even in other disciplines such as psychology.

However, there is also a strong case to be made that the subject matter of chemistry education – where the primary foci are teaching and learning – need to be explored and understood from more diverse perspectives than the phenomena studied in most chemical research (Taber, 2014). Student learning difficulties can be primarily related to the intrinsic challenge of the conceptual material and the nature of human cognitive processes. Yet often pedagogical ‘variables’ (ordering of topics, choice of teaching models and analogies) and cultural considerations (how technical terms are used in everyday language; whether learners are encouraged to question the textbook and teacher presentations) are relevant, as well as institutional factors (for example a school regime that influences student aspirations and/or motivation). It is quite reasonable, therefore, to expect that a range of studies that are at one level considering the ‘same’ core issues (the teaching and learning of chemistry) may actually take very different forms, and offer complementary insights into a complex situation.

Enquiry that is scientific takes place within a research tradition, building upon existing research, and adopting core commitments that are shared among a community of researchers (Lakatos, 1970). A shared core commitment in chemical sciences might be to the value of conceptualising matter as particulate at a submicroscopic scale to build models that can be used to develop explanations of the observed behaviour of substances in the laboratory. That is, whilst chemists might reasonably disagree over the details of the most appropriate molecular models and how to apply them, there are
few (if any) practising chemists who reject the use of explanations involving molecules, ions and electrons.

Such traditions, or research programmes (Lakatos, 1970), certainly exist in areas of science education. For example, a shared commitment among a community of researchers working on problems related to the present book would be that learners commonly form alternative conceptions of chemical ideas that significantly influence learning of the curriculum. This is one commitment of a perspective known as constructivism (or sometimes more specifically as pedagogic or psychological or personal constructivism). The present book will draw heavily on the constructivist programme (Taber, 2009) that has been extremely influential in science education for thinking about learning (Tobin, 1993; Jenkins, 2000). However, where Kuhn suggested that in the natural sciences the norm was for one such tradition to dominate within a research specialism at any one time, and Lakatos suggested coexisting programmes were necessarily rivals; alternative complementary approaches that examine different aspects of the complex natures of teaching and learning may augment each other productively within educational work, without necessarily being in direct competition.

1.2 Under-theorised Research

So, the argument here is that research in chemistry education certainly can be scientific and fit within the kinds of research programmes or traditions (sometimes labelled paradigms) said to exist in the natural sciences, but that the less orderly disciplinary structure seen in chemistry education could reflect a less mature scientific field or the greater complexity of what is being studied. It is likely both factors contribute (Taber, 2014). The less established nature of work in chemistry education is certainly detectable in some of the published research in the area reviewed by this book. Here, I will refer to two examples, one relating to terminology, and one to methodology.

Learners’ ideas have been described in the literature as misconceptions, alternative conceptions, intuitive theories, alternative frameworks, and indeed in a whole raft of other ways. Some scholars have offered careful analyses of particular terms, and arguments for particular preferences. Careful reading of some of these studies suggests the diverse terminology reflects significant differences in the conceptualisations of student ideas and thinking (see Chapter 14). However, as has long been recognised (Abimbola, 1988), usage of terminology is not consistent. That creates a challenge for researchers – but sadly one that is not always faced. So it is not unusual for studies submitted for publication, and indeed published, to simply adopt a term (commonly ‘misconceptions’ or ‘alternative conceptions’) as a catch-all, and completely sidestep the issue. Whilst the problem of terminology creates a challenge for authors and referees, and whilst writing intended primarily to inform teachers may well benefit from being uncomplicated, it seems questionable that those researching the issue
should write research papers that do not acknowledge and engage with what is recognised as a central problem in the research field.

1.2.1 **The Mental Register**

Perhaps even more significant is how some researchers into learners’ ideas and learning seem to adopt (at least in their research reports, and so one assumes in their research) oversimplistic ideas about how we might find out what others are thinking. This relates to what has been described as *the mental register* – the set of terms we use in everyday life to discuss mental events and processes (Taber, 2013). These terms are common in social discourse – and for the purpose of informal conversations we all know what we mean by such terms as ‘ideas’ and ‘thinking’, and we all know that usually the best way to find out what somebody else thinks, is to ask them.

However, if one is doing research into what students think, then one needs to take a more sophisticated approach that problematises the nature of thought and the epistemological question of how we can ever be sure we understand what someone else is telling us they are thinking. As with any area of research, an analysis of key ontological (*e.g.*, what counts as an idea?) and epistemological (*e.g.*, how do we get trustworthy knowledge about someone else’s ideas?) assumptions is essential to developing a methodological approach one can be confident produces valid and reliable data. A careful consideration of such matters is a topic for a book in itself (Taber, 2013) – but that does not excuse how so many research papers in chemistry education say virtually nothing about these key research issues, and treat the ‘collection’ and reporting of thinking and ideas as unproblematic.

1.3 **Some Things that Should not be Taken for Granted**

This book is then informed by a premise that professionals in chemistry education – such as those who are teachers or researchers (or both) – need to problematise things that we can too easily take for granted. Indeed, this is part of the rationale for research and scholarship. We all know, at some level, that we teach concepts – and can readily list some examples – but it may not be so easy to define what we mean by a concept, or explain what kind of entity a concept is, such that we can take that into account in our work. This might be compared with the period when atomic theory was gaining acceptance, such that chemists started to consider that matter was made up from atoms, but before there was a strongly evidenced model of what kind of entities atoms were best considered to be.

A core focus of education is learning, and again those working in chemistry education know – in general terms – what they mean by learning, and may be quite expert in applying formal techniques supposed to assess that learning. However, professionals will also be aware that such formal
assessments often produce simple output measures (78%, grade C +, a 2(i) classification, etc.) that put aside questions of what learning really is, and rely on measuring it in terms of behaviours: getting the right answers in tests. Yet research has shown that slight changes in context or question phrasing that seem irrelevant to the expert often lead to students answering test questions quite differently (Palmer, 1997; Taber, 1997): what does it mean to say a student has, or has not, learnt something in these circumstances?

Research looking for learning gains during educational innovations often use a pre- to post-test design that incorporates delayed as well as immediate post-tests. If, as can be common, students get the correct answers immediately after being taught the module, but then give wrong answers some weeks later (Gauld, 1986), we need to consider what is a sensible criterion for judging the learning to have occurred (and if we make the judgement on an immediate post-test, do we then consider then some kind of ‘unlearning’ to have then occurred?) Sometimes learning gains are actually greater in delayed measures – as something happens in the learner’s brain in the weeks and months after teaching is completed that means their test performance improves after some kind of incubation period. So how can we understand the influence of teaching if it may have effects that are not apparent till long after the teaching episode happened?

1.4 What Do We Know, and What Do We Need to Know?

This book then seeks to offer an examination of conceptual learning in chemistry that attempts to move beyond what we might readily take for granted: to explore what we know (and what we do not yet know) about the nature of chemical concepts, how learning of such concepts occurs, and how teaching can be informed by such considerations to bring about more effective learning.

At one level the treatment here may be considered philosophical, if not in a formal sense (there are much better qualified candidates than the present author for undertaking formal philosophical analysis). However, this book is centrally concerned with questioning what we know (or, sometimes, assume we know) about a core feature of the chemistry curriculum, chemistry concepts, and about the processes of teaching and learning those concepts.

The book is intended to inform those working in chemistry education, whether as researchers or teachers or both, and has been written with such colleagues in mind. I very much hope that this book will be read and understood by many chemistry teachers (whether teaching in a middle school or on a post-graduate programme or somewhere in between) and will substantially inform professional thinking and so teaching practice. However, driven by the view expressed above that sometimes research in chemistry education has been under-theorised and so is less rigorous and
useful than it might potentially be, there has been no attempt to simplify technical language or avoid complications that are relevant to the core issues discussed. Rather, to support readers, the author has liberally employed pedagogic devices such as analogies and metaphors where these seemed useful (e.g., “This might be compared with the period when atomic theory was gaining acceptance...” above). This has been done in the spirit that teachers are advised to adopt (see Chapter 12), as offering starting points for thinking about ideas that may be unfamiliar to some readers.

Chemistry teaching is a highly skilled job that draws upon a body of specialised knowledge. The chemistry teacher needs good subject (i.e., chemical) knowledge, a good understanding of the students they are teaching, and what has been termed pedagogical content knowledge or PCK (Kind, 2009) – knowledge of pedagogical ideas worked through within the specific teaching topic. Just as chemical knowledge is specialised knowledge where the teacher needs to keep up with recent developments, PCK is a specialised body of knowledge that is being continuously developed by reflective teachers (Taber, 2018b). That is what would be expected of any area that seeks to be considered scientific, whether within chemistry itself or the increasingly active area of chemistry education. This volume can contribute to teacher PCK as well as offering a survey of an important area of chemistry education research for those who look to take this field of research forward.

1.4.1 Some Orientating Questions for the Reader

If a book of this kind is seen as a scholarly examination of its topic, then useful questions in the context of the present enquiry might be:

- Are there canonical chemical concepts?
- Do experts (chemists, teachers) share the same concepts?
- Can novices (students) be considered to acquire canonical chemical concepts?

1.5 The First-order Approximate Model of Conceptual Teaching

These questions are motivated by a naïve model of teaching that often appears to be grounded on assumptions that:

1. There are canonical chemical concepts that are agreed by experts, presented in curriculum, and held by competent teachers.
2. Students generally lack chemical concepts prior to formal instruction, but through effective pedagogy can be supported in acquiring canonical chemical concepts.
3. Teaching is successful to the extent that students acquire canonical chemical concepts.
This book will certainly not suggest that such a model has no value, as it is rather difficult to see how chemistry teaching can proceed without some such general scheme. Yet it will be argued that each of these three points are problematic. At best, 1 and 2 are gross simplifications (as will be illustrated in this volume), and, once that is acknowledged, then care is indicated in how 3 is applied in evaluating teaching.

I am going to suggest that this model, points 1–3 above, should be considered a ‘first-order approximate model of conceptual teaching’. It would be disrespectful to generations of teachers who have operated under such working assumptions to describe this model as being zeroth order, as it clearly works to some extent, as least most of the time, with some students – but it includes a high level of simplification that may retard high-quality, refined work. One purpose of this volume is to suggest what a more sophisticated model, drawing upon research and scholarship in chemistry education and other fields, would be like.

References


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