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REFLECTION

Identifying research foci to progress chemistry education as a field

Keith S. Taber

Faculty of Education, University of Cambridge, United Kingdom

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Abstract Chemistry education is now increasingly seen as an academic field of scholarship in its own right. This article suggests two important principles to be taken into account when considering the question 'What should be the key foci for chemistry education research (CER)?'. The first of these applies a typology that divides research into chemistry classrooms as inherent ('essential'), embedded ('entangled') or collateral ('incidental'), according to the extent to which the research is conceptualised in terms of issues that arise in teaching and learning the specific subject matter of chemistry. It is important for the development of the field that inherent CER is particularly encouraged. The second principle relates to what makes a field scientific. Here it is suggested that research needs to have a programmatic nature so that the field does not just accumulate more studies, but is seen to progress by allowing new researchers to effectively be inducted and then build upon existing work.

PALABRAS CLAVE
Investigación en educación química;
Educación química como campo;
Programas de investigación

Identificando los enfoques de investigación para que la educación química progrese como un campo de estudio

Resumen La educación química se está estableciendo como un campo académico con su propia identidad y características. Este artículo sugiere dos importantes principios que deben tomarse en cuenta al hacer la pregunta: ¿cuál debería ser el enfoque de la investigación en educación química *(Chemical Education Research)*? El primer principio aplica una tipología que divide la investigación en las clases de química como inherente («esencial»), incrustada («involucrada»)

E-mail address: kst24@cam.ac.uk
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o colateral («incidental»), de acuerdo con el grado en el que la investigación se conceptualiza en términos de asuntos que surgen en la enseñanza y el aprendizaje de contenido específico en el área de la química. Para el desarrollo del campo de la educación química es importante que se favorezca la investigación en educación química clasificada como inherente. El segundo principio se relaciona con qué es lo que hace que un campo sea científico. Aquí se sugiere que la investigación necesita tener una naturaleza programática, de forma que el campo no solamente acumule más estudios, sino que progrese al permitir que los nuevos investigadores sean inducidos al campo y construyan sobre el trabajo existente.

This invited article addresses the question of 'What should be the key foci for research studies in chemistry education?' It is not suggested that any academic field should be regulated in the sense of people being told what to research and study – a field must evolve according to the research interests and concerns of its community. However, the research of individuals and groups is inevitably subject to influences that channel their work. Senior colleagues' views, editorial policies, referee opinions, funding body priorities, supervisor and mentor opinions, and so forth, will impact upon decisions about what to research, and how to go about it, especially those made by younger colleagues entering a field.

It seems important therefore that the scholarly chemistry education community engages in debate about how it understands the field of chemistry education so that dialogue and considered reflection, rather than simply personal hunches, inform how the field, and its priorities, are presented to new researchers. It is intended that this article will make some modest contribution to such a conversation among colleagues.

This seems a good time for such a conversation to be encouraged. Chemistry Education is developing its presence internationally and is becoming widely recognised as a research field with its own character and identity. Such a progress is inevitably a gradual one, but just as science education slowly established itself as an international research field (Fensham, 2004), so chemistry education is increasingly being seen as more than just a part of science education (Gilbert, Justi, Van Driel, de Jong, & Treagust, 2004). Chemistry education research (CER) will rightly remain located within science education research (SER), and indeed within the wider field of educational research (ER) – but needs to be understood as something more than just those SER studies that concerns chemistry education.

This is important if we consider the motivation for recognising a specialised field, one which responds to pressure from both the practitioner and the academic sides. In some countries chemistry teachers are just chemistry teachers and do not usually teach other subjects. From that perspective, conferences and publications about chemistry education seem justified, even if they simply represent any ER carried out in chemistry teaching and learning contexts. In other countries (such as England, my own country) the main school curriculum subject is science, and in most schools there are science teachers teaching chemistry who are not just teachers of chemistry. Chemistry specialists will often teach outside chemistry, and indeed, in many schools at least, chemistry topics will often be taught by science teachers who are not chemistry specialists. In such curriculum contexts, the need for a specific field of CER may seem less obvious.

The article starts by considering the issue of publishing articles in the international research literature, and why a paper might be considered as specifically CER. This leads to the discussion of a simple typology of three different levels of CER. This is used to argue for the importance of encouraging research into foci that are essentially – intrinsic to – CER, and indeed establishing research programmes around such inherent CER foci.

What makes a research manuscript count as SER, or CER?

Academics are often under pressure to publish in journals considered 'academic' rather than professional (although it might be argued that the best journals are those that cross over between the communities of researchers and classroom practitioners). Referees for prestigious research journals that can only publish a minority of submitted material will sometimes recommend rejection of a manuscript on the basis of it being too specialised. In the case of the top science education journals, authors may be told that their contribution was of too narrow interest for a general science education journal and they should look to find a more specialised journal – perhaps a chemistry education journal.

This argument, by itself, seems a little dubious considering the articles that do get published in such journals – many are based on research undertaken in a specific context: a particular national system, a particular phase of education, a particular science topic (i.e. usually a topic that is clearly from chemistry, or is part of biology, or physics, or geology etc.). This might suggest that referees recognise particular areas of research as inherently CER (and others as inherently physics education research, etc.) and others as more general SER. However, if so, the criteria for something being at core CER rather than SER are seldom made clear and therefore are presumably tacit. Scientists, students, and educational researchers, all draw heavily on implicit knowledge (Brock, 2015; Taber, 2014c) – but within a research community it is more helpful if evaluative criteria can be made explicit.

So this raises the question, what makes something inherent CER?

It seems likely that — assuming referees are making principled evaluations (rather than simply considering a paper about a teaching topic they are unfamiliar with as being too esoteric) — the presentation of work within a manuscript may be very important. Given that many SER articles are reporting from teaching and learning in particular topics, there is an issue of shifting from the local context where the research was carried out to make it clear why work has wider significance to readers: that it is theory-directed and not just context-directed (Taber, 2013a). That is, there needs to be a line of argument for new knowledge of the form that although the research was carried out in *this* classroom, with *these* students, taught by *this* teacher, in *this* school, learning about *this* topic, preparing for *this* examination (etc.) — the research offers generally applicable theoretical knowledge which has been abstracted from the context and is therefore of wider relevance.

Such a line of argument would make a case that the research reported has a wide range of potential application: this could be within chemistry classrooms, or more widely within science classrooms, or even more generally across curriculum subjects. It is suggested here that whether a particular study is considered to fall within CER rather than being of more general relevance should depend upon the extent to which it addresses specific key foci of CER.

Table 1 A typology of educational research in chemistry teaching and learning contexts.

Type of study	Status of research focus in terms of teaching subject	Description
Inherent	Essential	Research is focused on an issue which intrinsically arises from the specifics of the teaching subject
Embedded	Entangled	Research is focused on a general educational issue, but which has been conceptualised for the study in terms of the specifics of the teaching subject
Collateral	Incidental	Research is focused on a general educational issue, and the teaching and learning context simply provides a convenient data collection opportunity

A typology of research in subject based teaching and learning

I have suggested elsewhere a typology of articles submitted for consideration by chemistry education journals, which considers three levels of CER (Taber, 2013d). The typology could be applied just as readily to SER or physics education research, or indeed mathematics education research, and so forth, as it ask about the relationship of the research focus to the specifics of a teaching subject (see Table 1). The motivation for producing this was undertaking editorial screening on manuscripts submitted for publication in *Chemistry Education Research and Practice*. As with most research journals, many articles are submitted which are not considered suitable for peer review and are rejected on editorial screening. Peer review involves asking busy colleagues to spend time evaluating a manuscript, when often a quick look shows that a submission is not suitable for the journal and it would be inappropriate to ask peer reviewers to undertake a detailed evaluation.

Two common reasons for rejecting articles for *Chemistry Education Research and Practice* on editorial screening are that they are not about education, or they do not report research. The journal receives for consideration papers which have no educational focus at all: often these could reasonably be described as chemistry studies, but are chemistry research, not ER. Other articles are about chemistry, but written to inform teachers (or students) about some chemistry-related topic. There are suitable places to publish such articles, but they do not fit in a journal focused on CER.

Other manuscripts do report work in chemistry education, but cannot really be considered as research. The journal has criteria for what counts as a quality research study (Taber, 2012a), and submissions that describe educational innovations that are not well motivated by a review of relevant literature, or which do not have an explicit well-considered research design so that data collection and analysis respond to well-framed and motivated research questions, are not suitable for publication in an international journal. Whether such features of a study are well done is a matter for evaluation in peer review, but sometimes these features are completely absent, and then asking colleagues to evaluate the study would not be a good use of their time (or their goodwill).

So there are some categories here of submissions which clearly do not make the grade. However, there was another issue about some submissions which worried me, where the manuscript did clearly report work in chemistry education contexts, and was clearly education research, but where I was not sure the work should be published in a CER journal such as *Chemistry Education Research and Practice*. My concern was whether such studies were actually 'at heart' CER or simply ER undertaken in chemistry classrooms. I was not sure that some submissions, even if sound and useful research studies, addressed foci that were essentially chemistry education. This of course relates to my central question in this article, introduced above: 'What should be the key foci for chemistry education?'

This led to suggesting the three categories of 'inherent', 'embedded', and 'collateral' CER. The observation behind this typology is that many studies in science or chemistry education could be readily transferred to other teaching and learning contexts (you could delete any references to the specifics of what was being studied, without undermining the study), whereas some only make sense within the teaching context. It is possible to see this as a matter of a continuum of the extent to which the focus of a particular study is something essential to the teaching and learning of that specific content, rather than being a general teaching and learning issue (or indeed an even broader issue). However, having a typology of three categories is a useful tool for making 'first-order discriminations' along such a continuum.

So within education, researchers explore a wide range of issues, such as:

- how teenagers can be engaged in learning traditional academic subjects;
- the level of challenge students meet in the classroom – for example in terms of Bloom's (1968) taxonomy of educational objectives in the cognitive domain or one of its revisions (Anderson & Krathwohl, 2001);
- the engagement and attainment of students from different socio-economic backgrounds within school;
- the (gender, ethnic) diversity of people shown in textbooks;
- etc. . . .

These and many other such issues are perfectly valid and often well-motivated foci for ER studies. They are not inherently CER issues, or even SER issues. However, such issues should be explored – and indeed should certainly be explored in chemistry classes as well as in other subject teaching contexts. Whether studies of this kind, carried out in chemistry classes, should be considered embedded CER (deserving a place in the field) or collateral CER (not strictly part of the field) depends on how they are set up.

One can imagine a researcher exploring the degree to which students in classes were faced with tasks requiring higher order cognitive skills and who undertook research in one or more chemistry classes. If the study simply reports the frequency of opportunities for students to evaluate, criticise, synthesis, etc., then even if it was based in a chemistry classroom, this is collateral CER – research that concerns general educational issues, that happens to be set within a chemistry teaching and learning context. Such a study would not really belong in a CER journal. Indeed, given the high level of variability between classrooms, a study that simply reported such outcomes in one classroom would probably not deserve publication at all, unless it was focused on developing and demonstrating a new methodical approach for exploring the issue. More sensible here would be a survey of a representative range of classes.

Even if the research reported a comparison of the results from a well planned sample of classes in chemistry alongside similar samples from other subjects, and the results showed the profile in the chemistry classes was distinct (for example, perhaps a much lower level of challenge than the same pupils faced in other curriculum subjects) the study is not really CER, but rather a general educational study that should be of interest to the chemistry education community.

What could shift such a study from being collateral, almost incidental, CER, to being embedded CER, would be if the research was not just the type of study that would tally up tasks in terms of a general educational model, such as Bloom's typology, even if across many chemistry classrooms, but rather one which explored how the nature of the chemistry content might be impacting on teachers' choices of student task framing. It is embedded CER when it relates the general educational issue to *what is particular* to teaching and learning chemistry – such as asking 'Is there something about the topic of redox which might encourage teachers to set tasks that focus on recall and application, rather than developing more challenging classroom activities?' Arguably embedded CER is suitable for publishing and reporting in CER outlets (conferences, journals) whereas collateral CER is general ER and should be disseminated accordingly in more eclectic outlets.

There are a good many educational issues which are relevant to classroom teaching and learning, and where there is potential for worthwhile, quality embedded CER. Bloom's taxonomy and focusing on higher order cognitive tasks in learning is certainly one example. The importance of the dialogic in teaching is another (Scott, 1998). Vygotsky's notion of the 'zone of next (proximal) development' and how this might be utilised to scaffold learning is another. The value of multi-modal communication in teaching and learning is another (Jewitt, Kress, Ogborn, & Tsatsarelis, 2001). The incorporation of active use of digital technologies in classroom learning is another. There are many more. The point is that all of these topics could be explored in chemistry classrooms either for carrying out research with general educational aims and using that context as simply a convenient location: or for exploring the focus in the chemistry classroom, seeing that particular context as a complex system where the general educational idea (scaffolding, or whatever) interacts with the particulars of teacher, class, institutional context, curriculum context, language context . . . and subject matter (Taber, 2012b). If the researchers simply report that work was undertaken in a class where students were learning about acids and bases then that is purely incidental. However, if they explore how the chemistry subject matter, and the teacher's chemistry pedagogic knowledge and skills, impinge upon how scaffolding (or whatever) is enacted, then the research is embedded in chemistry education and becomes part of the field. In embedded research it critically matters that the class were learning about acids rather than about architectural styles in the classical world, or art of the Italian renaissance, or antitrust economic policies.

The need for intrinsic foci for research in chemistry education

There could clearly be an active and valuable research domain based on embedded CER. Such an area of activity might seem to be responsive rather than proactive – largely following trends in the wider province of ER. It might therefore also be considered 'top-down' rather than 'bottom-up' in that the agenda derives from (and so might be led by) the subsuming area of research (see the top part of Fig. 1). It might be thought that science education currently has something of this character despite being well-established. For example, one of the major handbooks for SER, the *Second International Handbook of Science Education* (Fraser, Tobin, & MacRobbie, 2012) includes a good many chapters which might be seen as about general educational issues rather

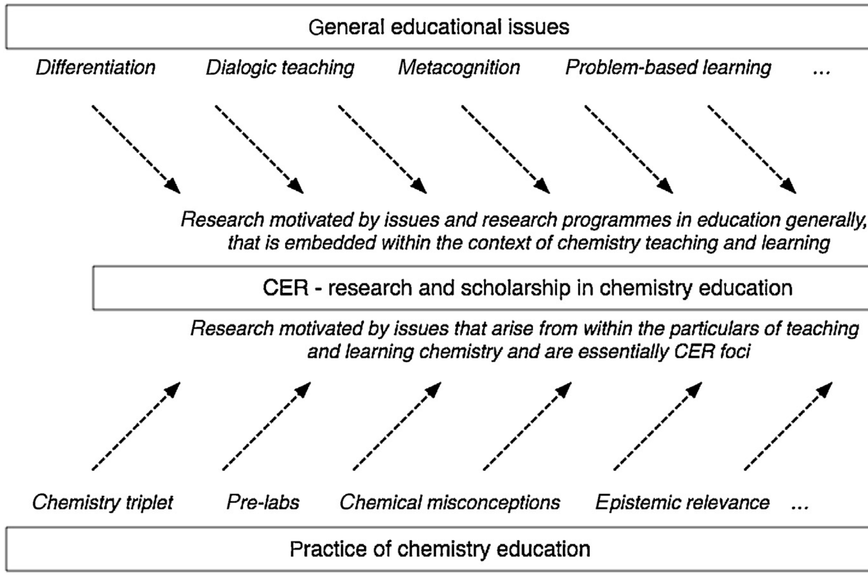

Figure 1 If CER is to have a strong identity as a research field it needs to develop inherent CER research programmes (i.e., deriving from issues that arise intrinsically from teaching and learning the subject) as well as respond to wider trends by including research on general issues of interest embedded within the specifics of chemistry education.

than reviewing work in science education (Taber, 2014b). These contributions offer perspectives that could inform research in science education, rather than describing areas of research arising from particular concerns within science education as a distinct practice. Whilst such issues and perspectives may certainly be relevant and important, and have considerable potential for informing better science teaching – they potentially dilute the sense of SER as a field with its own identity.

These general issues represent important concerns for all those working in education, and certainly offer worthwhile and fertile themes for research in science education, but if they dominate SER then that area of activity is less a coherent research field than just a subject-related subsidiary of ER more generally. Such a comment could be criticised as supporting the notion of different specialists working in their own silos and not looking at the wider picture, and could even be seen as encouraging 'empire building' that looks to support careers (a distinct field needs it own leaders) rather than responds to the needs of those who we work to educate.

However, the history of science makes it clear that progress in science depends upon both the increasing specialism of fields of research that develop their own characters – in terms such as Kuhn's (1974/1977) disciplinary matrix – *as well as* healthy cross-fertilisation of ideas across fields and disciplines. Indeed Kuhn (1977) referred to the 'essential tension' that exists in science between the need for developing traditions to guide productive work and being able to break out of those traditions when better alternatives are identified. The argument here is not that CER (or SER) should become insular and largely introspective: but rather there needs to be a balance between the adoption of ideas and concerns from beyond the field with the development of particular foci that arise from the specifics of teaching and learning chemistry (see Fig. 1). Without the latter, we do not really have a field of CER, just the use of a few furrows in a larger field of ER. This leads us to ask if there are areas of academic concern arising out of the practice of chemistry education that might be suitable foci to progress the CER field. These need not be exclusive issues of no potential relevance to other areas of the curriculum, but they need to be concerns that have arisen out of the practices of teaching and learning chemistry as a subject and so have been conceptualised from within that context – rather than simply borrowed and applied from elsewhere. By their nature they may draw on specifics. So teaching conceptual material and motivating students, for example, are issues across the curriculum: but none-the-less have arisen as foci of concern from within the teaching subject in relation to teaching particular topics.

Intrinsic concerns of science education

There certainly are issues within both science education and more specifically chemistry education that offer key foci for a field. Within science education two such issues might be practical work and socio-scientific issues.

Teaching science usually involves student practical work. Arguably something intrinsic to science as an activity is the interplay between theory and practice. Science progresses by developing theory to explain and understand observations, and then designing empirical work to test and develop theory (and so on). How to best use the laboratory in teaching science, so as to support learning and offer an authentic experience of science is a core concern in science education practice (Hofstein & Kind, 2012).

Science develops new (theoretical) knowledge of the world, but that knowledge is widely applied – in new medical treatments and in more destructive weapons; in schemes that damage the environment, and in schemes to protect and recover the natural environment, etc. Science *qua* science has no view on the moral value of its applications – but people (including people who are scientists) should have views. If science education prepares people for citizenship (Sheardy, 2010) then it needs to support them in engaging with socio-scientific issues where judgements need to be both informed by scientific knowledge, *and* draw upon extra-scientific values (Sadler, 2011). Applying this type of judgement invovles considerable cognitive maturity (Perry, 1970), and teaching for developing the requisite thinking skills is a challenge.

It is clear that these examples of SER foci apply in chemistry education as much as in teaching other science subjects. However, if CER were to simply explore SER foci, we again have the questions of whether CER can really be understood as a research field in its own right, rather than just the application of SER within particular (i.e. chemistry) teaching and learning contexts.

Intrinsic concerns of chemistry education

Again, we may find that intrinsic foci of CER are not completely unique compared with other areas of ER, but they should be conceptualised in terms of specific issues arising from the teaching subject. I suggest a few candidates here.

One focus of scholarship in teaching and learning chemistry is the 'triplet' – that understanding chemistry involves engaging with the macroscopic, submicroscopic and symbolic (Johnstone, 1982). When this idea was proposed it was suggested that physics and biology education had their own, somewhat different, analogues, but it is within chemistry education that this idea has become a major focus (e.g., Talanquer, 2011). The issue has been explored in various ways, but suggests that chemistry looks to explain observable phenomena (e.g. burning) that are redescribed at the macroscopic level in formal technical terms (e.g. combustion, oxidation) before being explained in terms of abstract theoretical models (i.e. particle theory). This is clearly a powerful tool for chemists, but a challenge for students and their teachers. Chemistry also uses extensive specialist representations, some of which play a role in bridging the molar (macroscopic) and molecular descriptions of the chemistry (Taber, 2013c). This offers intrinsic foci for research into teaching and learning that is essentially a concern of chemistry education.

Another candidate might be the chemical demonstration (Lister, 1996). Where the issue of practical work is of major interest within SER, the use of demonstration experiments in teaching has been seen as a strategy of particular relevance in chemistry teaching (though, note, not as a replacement for student practical work). Another focus of current research in teaching chemistry and other subjects is the use of flipped learning (where homework is not used to follow a class to apply and test leaning, but occurs ahead of class to prepare students for engagement in active learning in the classroom) which has proved a popular idea in teaching chemistry (Seery, 2015). This notion has a particular cachet in chemistry where it has long been proposed as a way to make undergraduate laboratory work more effective (Johnstone, Sleet, & Vianna, 1994). Within school level chemistry it has been argued that learning abstract theoretical concepts might be made more engaging for some students by seeking 'epistemic relevance' by using well-chosen lab work as a motivation for developing theory rather than as a supposed illustration of it (Taber, 2015).

Another focus is the nature of student thinking about chemical ideas. As in other sciences, students commonly form alternative conceptions (or 'misconceptions') or even extensive alternative conceptual frameworks of ideas (Kind, 2004; Taber, 2002). Although this general issue applies across the sciences and beyond, research in this area intrinsically needs to be undertaken framed by the specific contexts of the particular concepts being taught. It seems that in general our concepts are 'melded' from the interaction of our direct experiences of the world, and formal learning mediated by language (Taber, 2013b). In physics researchers can point to much learning from everyday experience that might inform the development of (alternative) conceptions in areas such as mechanics (diSessa, 1993). We can see why most people develop alternative conceptions of how force relates to motion. Yet it is harder to see how implicit knowledge based on direct experience of the world leads to key alternative conceptions in chemistry (for example, why students become so wedded to the flawed notion that reactions occur so atoms can fill their electron shells). So although there is much research into student thinking about scientific concepts, we might expect CER in this area to have its own character and direction drawing upon the specific issues that arise in learning chemical concepts.

Taking a scientific approach – developing research programmes in CER

So it seems there are key foci that should be seen as cornerstones of CER as a field in its own right. If we want CER to be productive as a field we should look to encourage research in these particular areas. We should also seek to ensure that this area of research has a scientific character. This does not mean forcing research designs from the natural sciences onto ER – which would actually be an 'unscientific' thing to do given that experimental research is seldom the most appropriate approach to addressing ER questions (Taber, 2014a). Rather, research in mature sciences develops through traditions that establish something like Kuhn's disciplinary matrices, and in particular identify core (ontological and epistemological) commitments to inform identifiable programmes (Lakatos, 1970).

Researchers need to agree on the fundamental nature of what they are researching, and the kind of knowledge it is possible to develop about such matters, before they can plan studies. Ideally they will also agree on key terms and concepts that can be starting points for a disciplinary matrix to develop (which will ultimately offer new researchers to the field guidance to support their induction into the tradition). Without this, researchers will write at cross-purposes and lack common reference points for effective communication and evaluation of each other's work.

There may be room for competing, or (given the complexity of educational phenomena) complementary, programmes exploring the same foci, but without such a programmatic framework work falls short of a key criterion for scientific progress (Lakatos, 1970): the ability of different researchers and groups to build upon each other's contributions and contribute iteratively to developing knowledge within a field.

An interesting case is the work on the contingent nature of student learning in science – where despite considerable differences between researchers, there was a canon of literature which established a common basis for a constructivist research programme (Taber, 2009). Though far from a completely coherent body of work, this example does demonstrate how a scientific research programme can be set out and developed in education.

Taking CER forward

Chemistry education is not yet well established as a recognised area of scholarly activity in its own right in many countries, and is still forging its identity as an international research field. I would suggest three guidelines for developing CER as a field:

- Activity considered part of CER as a field should not include collateral CER, which is better seen as general ER that has been undertaken in a particular context;
- Unless a substantive amount of CER is 'inherent' rather than 'embedded', we cannot consider CER to be a mature field with its own identify;
- Identifiable research programmes should be developed around those key intrinsic foci of chemistry education considered to be of particular importance for improving the practice of chemistry teaching.

Conflict of interest

The author declares no conflict of interest.

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