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INVITED SPECIAL SECTION:
Contributions of Educational Research to the Practice of Chemistry Education
General issues of science/chemistry education

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SECURING A FUTURE FOR CHEMICAL EDUCATION

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ABSTRACT: The ideas of chemistry are not getting the attention they deserve in either formal or informal educational provision. It is argued that an improvement in this position requires the further development of the nature and quality of chemical education in the light of research. An established typology of research is used to show that the range of types of chemical education research that has been conducted is too narrow to support this development. There is evidence that even existing research has too little impact on the practice of chemical education. A second typology is used to discuss the range of levels and forms of impact. Finally, it is argued that education through, with, and about chemical education research is needed in the professional development of chemistry teachers, if these situations are to improve and chemical education is to face a brighter future. [*Chem. Educ. Res. Pract.*: 2004, *5*, 5-14]

KEY WORDS: *research typology; research-use typology; professional development*

INTRODUCTION

Given the importance of chemistry in science, industry and people's personal lives, it comes as a great shock to realize that education in and about the ideas of chemistry, what is usually called 'chemical education', currently faces a range of challenges, even threats, throughout the world. The increased range of knowledge competing for inclusion in formal education (in schools, universities, vocational colleges) is leading to the separate major sciences (chemistry, physics, biology) being compressed into one unit, and a smaller unit at that, of the curriculum. In these circumstances, the amount and proportion of time devoted to chemical education is gradually being eroded, not least because the ideas of chemistry are found difficult to understand by many students. Indeed, what chemistry should be taught, and how, to the majority of students, is still very problematic. The pace at which chemical research and chemical technologies advance are making it difficult to decide what should be included in the education of future specialists in chemistry. Lastly, it has become evident that the ideas of chemistry are badly under-represented in the provision of opportunities for informal chemical education, through books, TV programs, science and technology centres.

Gabel (1999) reviewed research on the teaching and learning of chemistry, with the aim of identifying possibilities to improve chemical education through research. She concluded that, although many relevant and interesting studies have been published, there is a need to do more research in areas such as curriculum development, the use of technology, and contextual approaches towards teaching chemistry. Moreover, arguing that research results only have had little influence on the way chemistry is taught, she concluded that "there is a need to focus on ways to incorporate current research findings into the teaching and learning of chemistry" (Gabel, 1999, p. 553).

The authors of this article have recently been involved in editing a book, called *Chemistry Education: Towards research-based practice* (Gilbert et al., 2003). The purpose of this book is not only to present a state-of-the-art review of the results of research of chemical education, but also to contribute to the improvement of chemical education by strengthening the linkages between research, development, and the practice of chemical education. The book thus addresses the concerns of the major 'stakeholders' in chemical education to effectively support the future development of the field. It is based on three principles: all aspects of chemical education should be clearly associated with research; the development of opportunities for chemical education should be both continuous and be linked to that research; and the professional education and training of all those associated with chemical education should make extensive and diverse use of that research.

This article, based on the concluding chapter of the above-mentioned book, focuses on possibilities of enhancing the impact of research of chemical education on the professional development of chemistry teachers, thus contributing to the improvement of the practice of chemical education.

THE CURRENT STATUS OF CHEMICAL EDUCATION RESEARCH

During the 1960s, the field of chemical education research had two distinct cognate origins. One was that it drew on ideas about the nature of curriculum, teaching, and learning, from the generic subject of 'educational research'. The other was that it drew on the specific subject matter and enquiry approaches of 'chemistry'. 'Chemical education research' was, at that time, either the application of the ideas of 'educational research' to the subject of 'chemistry' or vice versa. More recently, however, a degree of integration has been achieved between 'educational research' and 'chemistry' to give a more coherent approach (Kempa, 1992). This has been possible for two reasons. First, with the rise of constructivism, teaching and learning have come to be seen as more content-specific. This has legitimised inquiries into the curriculum, as well as into teaching and learning, in the specific area of chemical education. Second, the nature of chemistry itself has come to be seen both as problematic and distinctive (Wandersee & Baudoin Griffard, 2003). The notion that 'philosophy of chemistry' is just a particular example of 'philosophy of science' is gradually being abandoned and it is emerging as a distinctive epistemology for chemistry (Erduran, 2001).

Over the period in which the distinctive subject of 'chemical education' has evolved, perceptions of the nature of social research, of which educational research is a manifestation, have also changed. McInytre (1998) has suggested that there are five types of educational research, each of which has a different relationship to policy and/or practice, which we outline below. We have added some comments about their current incidence and the balance between them.

Type 1. Research explicitly intended to inform a subsequent development of new policy or practice in a specific area

There is a high proportion of this type of research undertaken, particularly where the subsequent development work does not ensue. There are lots of studies of 'alternative conceptions' in chemistry (Gabel, 1999; see also Box 1). The intention of such researchers was, we must assume, that methods to promote 'concept development' would subsequently be produced. In all too many instances, this has not been the case. Moreover, the chemical themes on which such research is based are the classical ones, with almost no attention being given to inter-disciplinary ideas - essential for the understanding of scientific themes currently discussed in everyday life (Jenkins, 2000).

BOX 1: *Example of Type 1 Research: Students' alternative conceptions about the covalent bond (see Taber & Coll, 2003).*

Many studies have documented students' conceptual difficulties in the area of chemical bonding. For example, Taber (2001a) found that by the time learners reach 16 years of age they have usually mastered a teaching model of molecules having covalent bonds, which are seen as pairs of electrons 'shared' by two atoms. However, students commonly have difficulties progressing *beyond* the notion of the shared pair of electrons: which is seen as something more than an image or metaphor. For many learners the shared electron pair *is* the bond, a notion which is somewhat lacking in explanatory power (Tsaparlis, 1984; Taber & Watts, 2000), and which does not provide a good basis for progression.

In another study, Taber (1998) reported that the explanatory principle that atoms form bonds in order to achieve full shells or octets is very common among 16-18 year old students – apparently replacing the younger students' ideas about string, glue and elastic. Molecules are usually assumed to arise from discrete atoms because the atoms *want* or *need* to obtain 'full outer shells' or octets. For many students a shared electron pair holds atoms together *because* it enables them to have octets of electrons. It has been reported that the notion of *valency* (which is seen by students as the number of bonds 'needed' to obtain octet structures) is imbued with an explanatory or causative power by some learners (Barker & Millar, 2000).

The existence of bonding which does *not* lead to atoms having full electron shells is consequently something of a mystery to many learners. These students are not able to understand – for example – why sulphur would 'want' to go beyond SCl_2 or SF_2 to give SCl_4 or SF_6, or why the chlorine atom in $AlCl_3$ would 'want' to share an electron pair to form a dative bond, when it already had all the electrons that it 'needed' (Taber, 2001b).

Type 2. The evaluation of existing policies or practices intended to inform subsequent decisions and actions

There is currently a low proportion of this type of research, with developments being undertaken but never researched. For example, in the key area of chemical kinetics, most of the articles have been published in professional journals emphasizing only new developments that have been produced and implemented in teaching, but without evaluation of their significance for the learning of the theme (Justi, 2003). However, there are also examples of projects where teaching materials were produced and put into use, after which their effectiveness in the classroom was evaluated with the aim to improving their capacity to support the learning of chemical ideas (see Box 2).

BOX 2: *Example of Type 2 Research (see Bennett & Holman, 2003).*

The majority of studies of the effects of context-based approaches to teaching chemistry on students' understanding have been comparative in nature, looking at the understanding of selected chemical ideas demonstrated by students who have followed context-based courses and students who have followed more conventional courses.

Barker and Millar undertook a longitudinal study of 400 upper secondary level students at thirty-six schools in England following post-compulsory advanced level (A-level) Chemistry courses (Barker & Millar, 2000). Within this group was a mix of students following conventional A-level courses and a context-based course, *Salters Advanced Chemistry*. The study employed a series of diagnostic questions on key areas of chemical understanding, administered at three points over an 18-month period. Understanding of the following chemical ideas was probed: elements, mixtures and compounds, conservation of mass and reacting masses, characteristics of chemical reactions, chemical bonding, energy changes in chemical reactions, rates of reaction, and equilibrium reactions.

The study indicated that there were no significant differences in understanding between the two groups, though the context-based approach appeared to offer a slight advantage in developing ideas about chemical bonding and thermodynamics. Common areas of difficulty across all courses also emerged, in particular with ideas about ionic bonding, inter-molecular forces and open system chemical reactions. However, the students who experienced the gradual introduction and revisiting of ideas (such as chemical bonding and thermodynamics) in different contexts at several points during the course appeared to develop better understanding of these ideas than students following more conventional courses.

In a study with slightly younger students, Ramsden (1997) gathered data from just over two hundred students at eight schools in England, just before they took their final public examinations at age 16. Of these eight schools, four used a conventional science course and four used a context-based approach (*Science: The Salters' Approach*). The diagnostic questions targeted four key ideas fundamental to an understanding of chemistry: elements, mixtures and compounds, conservation of mass and reacting masses, chemical change and the periodic table as a unifying theme. No significant differences in levels of understanding emerged between those students following conventional courses and those following the context-based course. However, certain ideas, most notably conservation of mass, were not particularly well grasped by either group.

Type 3. Action research, intended to achieve educational improvement in a particular context and to generate understanding of that and similar contexts

There is also currently to a low proportion of this type of research. Reports of action research are not widely found in the chemical education literature, probably because classroom teachers all too often lack the skills, incentive, and time, to conduct such studies. Even if they do conduct such studies, the formal education system does not provide teachers with any incentives to write-up their work for publication.

Type 4. Research intended to identify practices that are distinctly effective for achieving particular educational goals.

There is a relatively high proportion of Type 4 research, but it is concentrated in too few topic areas, mainly the recognised 'key topics' of chemistry, such as chemical energetics and chemical equilibrium (see Box 3). So far, however, there has been a comparatively small amount of research into the rapidly expanding use of computers in chemical education. As computers are increasingly used, for instance, to help students understand the dynamic

BOX 3: *Example of Type 4 Research: An effective way to introduce the concept of 'chemical equilibrium' (see Van Driel & Gräber, 2003).*

Van Driel, de Vos, Verloop and Dekkers (1998) designed an approach on the basis of an empirical study in The Netherlands which focussed on the identification of (1) the types of reasoning used by students (aged 15-16 years) in the context of the introduction of chemical equilibrium and (2) the teaching strategies that promote conceptual change in this respect. This study resulted in a series of teaching strategies aimed to address specific types of student reasoning in order to foster conceptual change.

First of all, these authors addressed the *reversibility* of chemical reactions. Simple chemical experiments were used to demonstrate that the direction of a chemical conversion may be reversed by an apparently minor intervention e.g., adding one of the products to a reaction mixture. This proved to be a powerful method of challenging students' conceptions. Many students appeared to be puzzled by the fact that the addition of a substance, which was already present in the mixture of reagents, resulted in an observable change. Moreover, they wondered why the products created by the addition did not immediately react in the opposite direction, resulting in yet another observable change (Van Driel et al., 1998, pp. 384-387).

Next, an exploratory discussion was organised about a system in which a reversible reaction had occurred. From this discussion, students were challenged to conclude that all the original reactants as well as the resulting products were present, while the system was at rest from a macroscopic point of view. In this study, it was found that students then accepted the *incompleteness of a chemical conversion* as an empirical fact. By relating this fact to their conceptions of excess quantities, students were then confronted with the anomaly of why the reaction did not proceed to completion, although all necessary conditions are satisfied for this reaction to continue. In this situation, students became dissatisfied with some of their present conceptions.

Next, the notion of *dynamic equilibrium* was offered as an explanatory model for the above anomalies. In order to adopt this conception, students had to accept the possibility that a chemical reaction may occur, although this is not indicated by changes at the macroscopic level. They then need to subscribe to the idea that two opposite reactions are taking place simultaneously. This idea appeared to present many students with either linguistic or conceptual difficulties. Specifically, some students reasoned in terms of *oscillating reactions*. By discussing this conception in relation to the empirical fact that the system is at rest, although both the forward and the backward reaction are likely to take place, students were stimulated to accept the concept of dynamic equilibrium. The idea that the two opposite reactions have to proceed at equal rates proved easy to accept, once they realised that this is a necessary requirement to explain the absence of macroscopic changes.

aspects of molecular representations, research is needed to evaluate how effective such strategies are, and especially how students' knowledge, skills, and attitudes, change when working in computer-based environments.

Type 5. Research aimed at generating new knowledge, the impact of which on practice is uncertain, diffuse, or long-term.

Once more, there is a low proportion of genuine, visionary, Type 5 research. Pressure for such 'blue skies' research will only occur when the need to innovate in the chemical curriculum is widely recognised in the community of chemists and chemical educators.

To these five types we would add a sixth:

Type 6. Research undertaken from a particular psychological perspective that is carried out on chemical education as an exemplary domain.

For example, Adey and Shayer (1994) looked at the implications of Piagetian psychology as a way of understanding the learning of the sciences, including chemistry, at secondary school level. There is a very low proportion of this type of research, probably because it can only take place effectively within partnerships between psychologists and chemical educators. Indeed, the politics and funding of universities make such collaborations difficult to produce and sustain.

The significance of this rough balance of types of research in chemical education must be seen against a background of there being just quantitatively too little chemical education research in general taking place (Dawson, 1994). As a benchmark, major industrial concerns, including those in the chemical industries, today spend some 5-15% of their turnover on research and development activities. For education in general, which includes chemical education, the figure is much, much, smaller. Perhaps the ‘production’ side of chemistry sees chemical education as a competitor for scarce research funds. In any event, the availability of funds for chemical education research figure is inadequate.

THE IMPACT OF CHEMICAL EDUCATION RESEARCH ON TEACHERS OF CHEMISTRY

The consensus amongst teachers of chemistry seems to be, in our experience, that research currently has far less impact on the development of theory, policy, or classroom practice, than the researchers in chemical education would wish. The available evidence supports this view. According to Gabel, “probably nine out of ten instructors” are not aware of the research on student misconceptions, or do not utilize ways to counteract these misconceptions in their instruction (Gabel, 1999, p. 552). Kempa (2002) has recently reviewed studies of Portuguese chemistry teachers which showed that, in order of declining importance, they drew on ‘personal experience’, ‘common sense’, ‘official documentation’, and ‘a consensus amongst professionals’ as sources of professional knowledge. The research literature was hardly mentioned. There is every reason to believe that similar results would be obtained in any country. Moreover, the situation is probably not very different for teachers of other subjects.

Kempa (2002) has proposed a six-level model of the impact of existing chemical education research on classroom practice. The chemical education research community can thus take some measures to increase this impact. Taking Kempa’s model as an organizing framework, we make a number of suggestions about how this might be done:

At *Level 1,* the chemistry teacher is unaware of (potentially relevant) research findings that thus, inevitably, have no impact on classroom practice. Research can be made more accessible to teachers by producing simplified and shortened accounts of a single piece of research for publication in teaching profession newspapers and the like. It could also involve transforming the results of Type 1 research (currently the major Type) into Type 4 outcomes, bringing the findings of relevant research together and addressing significant educational questions of immediate concern to classroom teachers. Thus a review of research in areas of specific interest can be associated either with generalised proposals for what might be done in classrooms (e.g. Monk & Osborne, 2000), or with reviews of innovations that have proved useful in practice.

At *Level 2,* the chemistry teacher is aware of (potentially relevant) research findings but shows no interest in them. Again, these research findings thus have no impact on practice. This situation may come about because the teacher does not currently face the problems addressed in the research. Access to a 'mediator' – somebody who both knows the literature and who has recent classroom experience – may help their relevance to be seen.

At *Level 3,* the chemistry teacher is aware of the research findings, but does not act on them because they seem irrelevant to his/her concerns or are difficult to implement. The perceived lack of relevance may be because the research has been too narrowly conceived. In order to address this concern, Jenkins (2000, 2001) has pointed to the need for sociological, historical, and economic elements to be included in studies that are too often simplistically 'classroom-focused'. Most research implications can be broken down into sub-sets, such that the teacher could begin to use the research by implementing changes on only some aspects of it. The 'mediator' could help here.

At *Level 4,* the chemistry teacher knows about the research, decides to build on the research findings in the classroom, but does so without any real changes taking place. This low-level impact of research – otherwise known as 'innovation-without-change' – tends to happen where no source of 'mediation' is available and where an innovation is imposed from 'those in authority'.

At *Level 5,* the chemistry teacher knows about the research and decides to incorporate some of the findings, resulting in a medium level of impact – some altered classroom practice. With the support of a 'mediator', say a university academic working in a collaborative, action research mode, perhaps all the implications can be worked through, given time.

At *Level 6,* the chemistry teacher knows about the research and, in a high impact utilization of the research, decides to use relevant findings to improve his or her classroom practice. This situation only seems to take place when a teacher has extensive collaborative support. One example of this level of impact was the progressive introduction of many of the elements of the model-based science curriculum into at least some schools in U.K. (Boulter & Gilbert, 2000). Another example was the reform of a 'chemistry for engineering undergraduates' course in Australia that drew on a wide range of research results and their developmental implications (Fensham, 2002).

The role of professional development of chemistry teachers

The pre-service and in-service education of prospective and experienced chemistry teachers can play a crucial role in bridging the gap between chemical education research and classroom practice. However, this requires the development and implementation of adequate professional development programs which, in our view, should focus on the following aims:

Increasing chemistry teachers' awareness of chemical education research

This would be done by providing opportunities for teachers to both read and discuss relevant research articles. Such discussions might, at least initially, be guided by questions such as: why was this piece of research conducted?; what are the particularities of the situation in which it was conducted?; what is the significance of its findings?; how might such findings influence policy and practice in the questioners' institution? Important sources of information are relevant articles from journals, such as *International Journal of Science Education, Science Education, Research in Science Education,* and *Journal of Research in Science Teaching*.

Improving the use of chemical education research findings by chemistry teachers

This can be achieved for several purposes and in several ways. For example, the conclusions produced from discussions about the implications of specific research findings can be used as the basis for the preparation of new teaching strategies and materials. Research findings about students' preconceptions can be used by teachers to design questions for use as pre-tests in their own classes. Similar questions can be added to teaching materials and assignments as a way of monitoring the change brought about in those understandings. As all such questions are intended to illuminate students' conceptual difficulties, it will be essential that their answers were discussed in the classroom. Indeed, helping teachers to analyse students' answers will enable them to achieve a better understanding of students' problems (Geddis, 1993).

Involving chemistry teachers in chemical education research

This can be done by inviting teachers to adopt the role of 'teacher-as-researcher' to undertake Type 3 research. In this approach, teachers investigate their own classroom practice in a systematic and intentional way. This activity would require teachers to understand the importance of research activities for the improvement of their professional practices. Common features of the 'teacher-as-researcher' approach thus include control or ownership of the specific questions or practical problems to be explored. It also assumes that they will decide on the actions that they will carry out, for instance, gathering information, collecting empirical data, and designing materials. The approach often incorporates group activities, such as sharing experiences and discussing results (Bell & Gilbert, 1996). Five ways have been suggested for the presentation of 'teacher research' for self- and peer-evaluation (Sweeney, Bula & Cornett, 2001). First, teachers write journals in which they document their classroom activities, subsequently drawing on them to make presentations to their peers. Second, teachers write essays in which they reflect on their teaching experiences. Third, small groups of teachers engage in discussion whereby they explore their experiences by examining particular issues. Fourth, teachers analyse students' answers to essay questions, or audio- or video-tapes of classroom activity. Fifth, teachers write short articles about research activities for chemistry teachers' journals. Feldman (1996) used activities such as 'anecdote telling' as a way by which teachers could share their knowledge, discuss new ideas for teaching and learning, and develop lines of systematic enquiry. He concluded that, since these activities are closely connected to the everyday work of the participants, they have the potential to become embedded in that practice, leading to its enhancement.

A WAY FORWARD

What we have tried to show in this article is that research can and does play a role in addressing the current shortcomings in the curriculum for, and in the teaching and learning of, the ideas that constitute the subject of chemistry. It can have an impact on the challenges that chemical education will face in the (near) future. However, for this address and impact to be effective, more research, of a broader range of types, more effectively disseminated, and more fully integrated into the teacher education process, will be needed. The challenges to the overlapping communities of chemists, chemical educators, and chemical education researchers, are considerable, but, in our view, necessary to strengthen and secure the position of chemical education in the coming decades.

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