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BEYOND PHILOSOPHICAL CONFUSION: ESTABLISHING THE ROLE OF PHILOSOPHY OF CHEMISTRY IN CHEMICAL EDUCATION RESEARCH

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Abstract. *The paper outlines some perspectives from the relatively new field of philosophy of chemistry and explores the implications of these perspectives for chemical education research. The paper is theoretical in nature and uses the review of literature as a methodological approach to synthesise a research territory for the applications of philosophy of chemistry in chemical education. The discussion begins with contextualization of the status of philosophy of chemistry in chemical education in general. Subsequently, the potential contributions of philosophy of chemistry in chemical education research are outlined. The argument is presented that the clarification and elaboration of important philosophical themes such as relativism and positivism are only one aspect of how philosophy of chemistry relates to chemical education research. Other contributions include the insights philosophy of chemistry can offer about the epistemological, linguistic and ethical aspects of chemistry - themes that have profound implications for how teaching and learning of chemistry are structured at the level of the classroom as well as how teacher education and curriculum design can be improved.*
Key words: *philosophy of chemistry, chemical education, interdisciplinary studies of science, teacher education, curriculum design.*

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Introduction

Treatment of philosophical perspectives in chemical education research has conventionally focussed on themes such as relativism, objectivism and realism (e.g. Herron, 1996). As an influential contributor to the newly emerging field of philosophy of chemistry, Eric Scerri of UCLA has maintained the thesis that such philosophical concepts have been misinterpreted in the work of some chemical educators, and at times, they are at odds with scientific ideas:

> 'I think that if one looks closely at the basic philosophical positions offered by some chemical constructivists, one sees many radical themes that are not only open to serious questioning but can also be construed as being anti-scientific' (Scerri, 2003, p.468).

Scerri further argues that one remedy to this philosophical confusion is more use of philosophy of chemistry in chemical education research. In Scerri's view, philosophy of chemistry not only can clarify the philosophical positions that are of concern to chemical educators, but also can illustrate the domain-specific characteristics of chemistry that distinguish it from other sciences like physics and biology.

I want to begin my discussion with some of the ideas Scerri presents in contextualizing the status of chemical education research, and subsequently, present an outline of how I perceive the contributions of philosophy of chemistry in chemical education research. I will argue that the clarification and elaboration of important concepts such as relativism and positivism are only one aspect of how philosophy of chemistry relates to chemical education research. Other contributions

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include the insights philosophy of chemistry can offer about the epistemological, linguistic and ethical aspects of chemistry, themes that have profound implications for how teaching and learning of chemistry are structured at the level of the classroom as well as how teacher education and curriculum design can be improved.

Status of Chemical Education Research

Scerri reflects on the status of chemical education research by highlighting how for some chemists, "research in chemical education represents a soft-option best suited for those who are not capable of succeeding in 'real chemistry' research" (p.468). He continues to argue that some of the blame in the low reputation of chemical education research among chemists can be attributed to the philosophical confusions demonstrated by chemical educators. While I acknowledge that such confusions do exist, I want to consider chemical education research beyond university chemistry departments to illustrate the diversity of the chemical education community. There are education departments all over the world most of which have specializations in science education where people can pursue PhD degrees in chemical education. There is extensive body of research in chemical education (e.g. Gable & Bunce, 1984). To perceive of chemical education research as a soft option to doing hard science of chemistry is reflective of lack of knowledge on the part of some chemists that there is a formalized discipline called "science education" with its own body of journals, conferences, societies as well as funding agencies.

Take for instance, the *American Educational Research Association* or the *Journal of the Learning Sciences,* which represent not only the academic forums where educational issues are shared and developed, but also include membership by cognitive scientists, educational psychologists, philosophers, historians and sociologists as well as embody expertise in assessment, instructional design and school management among others. Take, for instance, the funding agency the National Science Foundation in the United States which has provided funding for hundreds of projects that aimed to understand and improve the teaching and learning of science in and out of classrooms.

Chemical education research is an interdisciplinary endeavour. For instance, in formulating theories of learning, teaching and curriculum as well as in researching empirically based explanations for educational processes, chemical education research draws on a variety of disciplines such as philosophy, psychology, sociology and history (e.g. Erduran et al., 2004). Anyone who doubts the quality of research in chemical education can investigate more systematically and rigorously some key journals such as *Science Education, Cognition and Instruction* and *Journal of Research in Science Teaching*, and pay a short visit to the education departments which can be found in most universities worldwide. It is through constructive dialogue and objective investigations that miscommunication among chemists and chemical educators will be resolved, not through prejudice-laden and empty arguments.

It is also important to note that "school chemistry" is not the same as 'chemistry'. The goals and aims of education do not necessarily correspond to goals and aims of chemical research be them in the form of hard science or as an object of investigation by philosophers or historians. For instance, the historical progression of ideas in science may not be followed in the same order in the classroom for pedagogical purposes, yielding a vision of science devoid of historical context. However at times, sequences of concepts introduced in the classroom may serve learners' understanding if they do not come in the historical order. Indeed often science education discards many old theories and models in favour of recent accounts so as not to confuse students or impart potential misconceptions that have been dealt with throughout history by scientists. Overall, such approaches demarcate the purposes and processes of school versus institutional science. Furthermore, school science as advocated in important policy documents worldwide (e.g. National Research Council, 1996) is one that recognizes the right for everyone to be scientifically literate, not just those who will become scientists. Broadening the audience in chemical education raises many new problems for designing effective learning environments. Furthermore, the applications of basic disciplines such as philosophy, psychology, chemistry and sociology in the context of chemical education research demand some extent of translation of ideas to be useful and effective at the level of educational explanations. Let's take realism, as an example. It's one thing for chemical educators to define and understand realism in the way that philosophers do but another to make it workable in application to education. What, for instance, would count as a reliable piece of data from classroom conversations that would indicate the presence of realist ideology? How would we extend the theoretical definition of realism such that it could serve to capture empirically based statements?

Much work for chemical education researchers are situated in such spaces where they try to make sense of teaching and learning processes that are bound by theory from a basic discipline like philosophy and by empirical data from the classroom. If one does come across work that neither has a sound theoretical backing nor rigorous empirical basis, then this work is simply poor work, as can occur in any discipline not just education. Let me now turn my attention to how I perceive the dialogue between chemical educators and philosophers of chemistry can be placed on some constructive ground. What exactly is the role of philosophy of chemistry in chemical education research? What could be the contributions of philosophy of chemistry to chemical education research?

Role of Philosophy of Chemistry in Chemical Education Research

I have argued on numerous occasions that chemical education theory and practice would benefit from applications of philosophy of chemistry. For example, I have argued that models (Erduran, 2001; Erduran & Duschl, 2004), reductionism (Erduran, 2005) and laws (Erduran, 2007) provide example contexts where philosophy of chemistry can contribute to chemical education. However, foundations of philosophy of science were set by individuals who focused on physics in their analyses of science (e.g. Carnap, 1928/1967; Hempel, 1965). It is not surprising, then, that epistemological questions surrounding scientific knowledge have centered on physics.

Numerous philosophers of science (Scerri & McIntyre, 1997; van Brakel, 1994) are challenging the perspective that physics can serve as an exemplar in describing knowledge in other sciences. There is growing support that chemistry deserves a distinct epistemology (Scerri & MyIntyre, 1997; van Brakel, 2000). A new field, philosophy of chemistry, is emerging (Bhushan & Rosenfeld, 2000). In light of these developments in philosophy of science, the following questions are advanced. As chemical educators, how do *our* definitions of chemical knowledge compare to those recently raised by philosophers of chemistry? How are we defining chemical knowledge for the classroom? What chemical knowledge do we want students to learn? What are some other aspects of chemical practices that should be prioritised for learning? These questions are not only critical to ask at a time when chemical epistemology is taking momentum but they also offer an exciting challenge in application to everyday classrooms. I have raised such questions on numerous occasions but the significance of these arguments for chemical education has yet to be recognised (e.g. Scerri, 2007).

In the rest of this paper, then, my conceptualization of the applications of philosophy of chemistry in chemical education research is presented, being limited to secondary schooling, and in particular to middle-school level which has been the predominant area of my research interest (e.g. Erduran et al., 2004). However, some of the issues that I will raise will have implications for upper secondary as well as tertiary education as will be outlined in later sections. The paper is theoretical in nature and uses the review of literature as a methodological approach to synthesise a research territory for the applications of philosophy of chemistry in chemical education.

One could consider the applicability of philosophical concepts in the formulation of research questions in chemical education and the interpretation of empirical data that are collected from school-based research contexts. The issue then becomes, how can philosophy of chemistry enrich the theoretical and empirical study of education? For example in our recent work on argumentation (Erduran et al., 2004), we have used the scheme developed by philosopher Stephen Toulmin (1958) for the coding of verbal data from classroom conversations and student group discussions. In other words, the philosophical framework on argument has been applied to discourse analysis of empirical data from the classroom. The translation of theoretical ideas such as 'claim' or 'warrant' from Toulmin's framework such that they can be reliably identifiable in empirical data has been a critically challenging component of our work. In a similar fashion, the applications of philosophy of chemistry in chemical education research are bound to be full of challenges but also exciting new territories.

There are potentially many aspects of chemistry that philosophy of chemistry addresses which can be extended in application to chemical education research. In this paper, I will concentrate on three areas. These areas target some fundamental philosophical issues that concern epistemology, linguistics and ethics (Table 1). The questions generated for each category as well as the perceived application in chemical education research are not exhaustive but rather they are intended to outline an agenda for where philosophy of chemistry's contribution to chemical education research can be situated. Classrooms are places where knowledge is communicated. Classrooms are also places where ideals of citizenship and morality are revoked. Thus there is ample opportunities for chemical education to embrace epistemological, linguistic and ethical aspects of chemistry, and for chemical education research to investigate how these aspects of chemistry can be introduced in schooling.

Epistemology

With respect to the epistemological aspects of chemistry, questions can be raised regarding the content and structure of chemical knowledge including models (Erduran & Duschl, 2004). Some of the questions that would have relevance to chemical knowledge are the following:

Table 1. Contributions of Philosophy of chemistry to Chemical Education Research.

Aspect of Philosophy of Chemistry	Relevant Questions	Example Applications in Chemical Education Research
Epistemology	What is the structure of chemical explanations? What are the processes through which chemical knowledge is generated, evaluated and revised? What are the criteria by which chemical knowledge is evaluated?	Curriculum representing the nature and growth of chemical knowledge Teaching the nature of chemical knowledge Learning of the nature of chemical knowledge and growth of chemical knowledge Classroom formative assessments about nature of chemical knowledge Instructional design to promote the teaching and learning of chemical knowledge
Linguistics	What characterizes chemical discourse? What signs and symbols are used as tools in the representation of chemical knowledge? How is chemical knowledge communicated? What are the standards and means by which chemical knowledge is shared?	Promoting and supporting chemical discourse practices in learning environments Teaching and learning of symbolic systems Comparisons with everyday discourses
Ethics	What aspects of chemical knowledge relate to ethical concerns? What are the moral implications of chemical knowledge?	Development of citizenship through schooling Teaching and learning of value systems as they relate to chemical knowledge, its use and development

What is the structure of chemical knowledge? For example, what are features of models, laws and theories in chemistry?

What are the processes through which chemical knowledge is generated, evaluated and revised? For example, what criteria drive the formulation and revision of laws such as the Periodic law?

These questions target some central questions that concern the structure and development of chemical knowledge as well as the standards and criteria that are involved in the processes of knowledge growth. The educational applications can range from curriculum design to assessment practices at the level of the classroom. For example, what kind of feedback mechanisms can teachers establish in the classroom such that students' understanding of the nature of chemical knowledge is facilitated?

In a recent paper, I have argued that chemical laws provide a useful context for raising epistemological issues related to chemistry (Erduran, 2007). It is worthwhile to briefly review the nature of chemical laws and how they relate to laws in other science domains to illustrate how theories of knowledge can clarify and even define educational goals. As an example of the discussion on the nature of chemical laws, consider the so called "Periodic Law". Viewed from the perspective of physics, the status of the periodic system may appear to be far from law-like (Scerri & McIntyre, 1997). Significantly, the Periodic Law seems not to be exact in the same sense as are laws of physics, for instance Newton's laws of motion. Loosely expressed, the periodic law states that there exists a periodicity in the properties of the elements governed by certain intervals within their sequence arranged according to their atomic numbers. The crucial feature which distinguishes this form of 'law' from those found in physics is that chemical periodicity is approximate. For example, the elements sodium and potassium represent a repetition of the element lithium, which lies at the head of group I of the periodic table, but these three elements are in no sense identical. Indeed, a vast amount of chemical knowledge is gathered by studying patterns of variation which occur within vertical columns or groups in the periodic table. Predictions which are made from the so called periodic law do not follow deductively from a theory in the same way in which idealized predictions flow almost inevitably from physical laws, together with the assumption of certain initial conditions.

The implications for educational research include applications of such perspectives from chemical epistemology to curriculum, teaching, learning, assessment and instructional design, among others. For instance, the content and structure of the chemistry curriculum would be influenced by new insights into the nature of chemical knowledge. With respect to the example on the Periodic Law, the curriculum would need to acknowledge the approximate nature of laws in chemistry and the contrast of laws across the physical sciences. More concrete examples for curriculum design can be found in Erduran (2007).

Linguistics

Another potential contribution of philosophy of chemistry in chemical education research concerns issues that have to do with chemical linguistics. Example questions that would have consequences for applications in educational research include:

What characterizes chemical discourse? What signs and symbols are used as tools in the representation of chemical knowledge?

How is chemical knowledge communicated? What are the standards and means by which chemical knowledge is shared, critisized and compromised?

This area of research on linguistic aspects of chemistry is particularly relevant at this point in

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time when the science education literature is increasingly recognizing the value and role of discourse in learning processes (e.g. Kelly & Chen, 1999) as well as in the establishment of communities of learners who are engaged in particular science discourses (e.g. Lemke, 1990). A significant aspect of educational research would involve issues such as promoting and supporting chemical discourse practices in learning environments as well as investigations into the teaching and learning of symbolic systems in chemistry.

Many chemists themselves have recognized the significance of language and symbolism in chemistry. Roald Hoffmann, the Nobel prize winning chemist who is an exceptional scientist with diverse interests in history, philosophy and other aspects of chemistry, for instance, has argued on numerous occasions about the unique nature of chemical linguistics that is historically and culturally situated (Hoffman, 1995; Hoffman & Laszlo, 1991). An aspect of chemistry that spans its language as well as its epistemology is well illustrated by Pierre Laszlo in the following quote:

> 'A major obstacle to chemistry being a deductive science is that its core concepts very often are defined in circular manner: it is impossible to explain what an acid is without reference to the complementary concept of a base. There are many such dual pairs among the core concepts of chemistry. Such circulation of concepts, rather than an infirmity chemistry is beset with, is seen as a source of vitality and dynamism' (Laszlo, 1999, p.225).

Such particular features of language in chemistry are critical to identify particularly if we are to communicate to students a picture that is faithful to the domain of chemistry. The chemical language is rich in symbolism, conceptual relations and communicative tools. Future analysis from philosophy of chemistry on the nature and structure of chemical language will have similar implications for chemical education research, particularly with respect to the social and communicative aspects of the chemistry classroom. Promoting and supporting chemical discourse practices in the learning environment is but one goal that this area where philosophy of chemistry can be informative.

Ethics

The last aspect of philosophy of chemistry I want to take issue with concerns ethics of chemistry. Current landscape in science education both at the policy (e.g. National Research Council, 1996) and research (e.g. Zeidler, 2003) levels promote the education of individuals to be able to make informed decisions and justified moral choices on scientific issues ranging from genetically modified foods to environmental protection (Kovac, 2004). Take, for instance, the following questions:

> What aspects of chemical knowledge relate to ethical concerns?
> What are the moral implications of chemical knowledge?

An influential contributor to the ethical studies concerning chemistry, Jeffrey Kovac highlights the particular ways in which chemists' lives are defined by problems of ethics:

> 'Ordinarily chemists are not independent practitioners like lawyers and doctors, but instead work within institutions such as colleges and universities, government agencies and industrial concerns. As a result, they often have several roles. For example, I am both a chemist and a professor and each profession has its own history and culture. In industry a chemist is certainly an employee and might also be a manager. All industrial chemists must balance their ethical obligations to chemistry as a profession with their contractual and ethical obligations to their employers. In addition, all chemists are also citizens and human beings with the civic and moral responsibilities that accompany those roles. One of the goals of a philosophy of the profession should be to clarify the ethical responsibilities of chemists as chemists, as opposed to their responsibilities in other roles. Conflicts can occur' (Kovac, 2000, p. 217).

Chemists work in a variety of contexts and consequently are confronted with a broad array of ethical problems. The chemical industry is interlinked with societal questions and demands, and therefore gives rise to complex issues concerning the relationship of science and society. Kovac (2000) explores the relationship between professionalism and ethics. Since writing *The Ethical Chemist*, a collection of cases and commentaries for the teaching of scientific ethics to chemists, Kovac has been investigating ethics as an integral part of chemistry. In particular, he explores those aspects of chemical ethics that go beyond the demands of ordinary morality, the requirements of law and the pressures of the market. What are the ethical standards of chemists as scientists and why should they be obeyed? Furthermore, Kovac suggests that a healthy dialogue concerning professionalism and ethics is essential to a broader philosophy of chemistry. While a discussion of concepts is the core of a philosophy of science, science is, after all, public knowledge developed by a community. What is unique about chemistry as a science is partly a result of the uniqueness of the chemical community and its history. Studying chemistry as a profession will help reveal the essence of chemistry as a science.

While there has been much recent interest in the ethics of science, most of the literature is rather broadly conceived, treating science as a single enterprise (Kovac, 2000). According to Kovac, here is little, if any, recognition that each scientific discipline has its own perspective on professionalism and ethics. For example, David B. Resnik's book, *The Ethics of Science: An Introduction* (Resnick, 1998) for all its strengths, never discusses the differences between the various sciences. There is a substantial literature of casebooks designed to provide materials for courses in scientific ethics. Some of these, such as *Research Ethics: Cases & Materials*, edited by Robin Levin Penslar (Penslar, 1995), provide a broader philosophical introduction and cases in a number of disciplines, while others, such as Kovac's work (Kovac, 2004), focus on practical ethics in a single discipline. There is a tiny literature on ethics in chemistry, but the unique disciplinary culture of chemistry plays only a tacit role in these discussions, and only because most of the articles are by chemists whose perspective has been shaped by professional training in the field (Coppola & Smith, 1996; Kovac, 1996). Understanding of the nature of value systems among chemists and in the conduct of chemistry holds the potential to inform teaching and learning of dimensions of chemistry typically overlooked in education. For instance, one educational application would concern the question "what is the nature of moral reasoning in chemistry and how could such moral reasoning be incorporated in the curriculum?"

In summary, philosophy of chemistry with its numerous subfields is bound to have numerous implications for education, particularly given the epistemological, lingustic and ethical issues that touch on many aspects of teaching and learning. Given classrooms are environments that feed on knowledge, social and linguistic norms as well as affective features of the human condition, it is inevitable that in time, chemical education research will resort to philosophy of chemistry in clarifying problems and seeking solutions. IN the next sections, I will explore some implications relative to learning, curriculum design and teacher education.

Applications in Chemical Education Research

In an earlier article, we had outlined some implications of philosophy of chemistry for chemical education research (Erduran & Scerri, 2002) which I will briefly revisit here and elaborate with respect to epistemological, linguistic and ethical aspects of chemistry. In this work, we had suggested some potential contributions of philosophy of chemistry to theories of learning, curriculum design and teacher education. The reason for this emphasis was threefold.

First, application of philosophy of chemistry in chemical education research raises the question of what constitutes a learning trajectory when the focus of chemistry learning is shifted to new grounds such as epistemological reasoning. For instance, what would be the developmental patterns in students' thinking with respect to an understanding of how knowledge growth occurs in chemistry? We argued that future theories of learning will need to be informed by the evidence presented from both philosophy of chemistry and its application in chemistry education. Second, curriculum design and implementation have been, and continue to be, at the forefront of science education reform. The merging of curriculum design with chemical epistemology creates a new forum where constraints

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to educational reform can be reviewed and resolved (Erduran, 2001). Third, teaching involves the coordination of content knowledge of a domain and knowledge about the epistemology of that domain (e.g. Schwab, 1962). For chemistry teaching to be effective, prospective teachers will need to be educated about how knowledge is structured in the discipline that they are teaching. Practice and theory of future teacher education, then, will need to be informed by and about philosophy of chemistry. So how would the epistemological, linguistic and ethical aspects of chemistry apply to theories of learning, curriculum design and teacher education?

Learning of chemistry has conventionally been framed in terms of problem solving (e.g. Gable & Bunce, 1984; Lythcott, 1990), concept learning (e.g. Cros, Chastrette & Fayol, 1987; Nussbaum & Novak, 1979) and learning of science-process skills (e.g. Heeren, 1990). Learning of the epistemological, linguistic and ethical aspects of chemical knowledge call for a redefinition of learning in chemistry For instance, we have little understanding of what patterns might underly students' ethical reasoning in chemistry. Hence, the trajectory for learning "chemical ethics" would need to be redefined to include specifications from philosophical considerations. Concentrating on learning trajectories is particularly relevant when evidence from higher education is concerned. Students in advanced chemistry classes demonstrate having difficulties with many aspects of chemistry. For instance, in a study conducted by Cros and his colleagues (1987), 95% of a large sample of university students had difficulty interpreting the Bohr model of the atom. Could the sensitization of chemical education to epistemological, linguistic and ethical aspects of chemistry help resolve such problems in students' thinking?

Promoting the inclusion of philosophical perspectives in the chemistry curriculum suggests a departure from common approaches, and hence offers a new perspective for future curriculum development efforts. Conventional approaches in curriculum design have typically included emphases on content knowledge (e.g. problem-solving in the context of substances, atomic structure and chemical reactions) or societal aspects of chemistry (e.g. effects of chemical pollution on the environment) in the writing of instructional activities. Numerous curriculum reform efforts have been based on these approaches such as the Interdisciplinary Approach to Chemistry, CHEM study, Nuffield 'O' Level Chemistry and ChemCom. Through contributions of ideas from philosophy of chemistry, curriculum design can begin to address the traditionally alien forms of chemical knowledge such as chemical linguistics. For example, what curricular formats would support the execution of authentic chemical discourse in the classroom? How can the chemistry curriculum be structured so that learners develop an appreciation of "chemistry talk"?

There is considerable evidence (e.g. Cros et al., 1987; Ross & Munby, 1991) that even after innovations in curriculum design, numerous factors constrain change in teaching. Of particular relevance to the central thesis of the present work is obstacles to reform that concern teachers' background in chemistry as it relates to chemical epistemology, linguistics and ethics. Schwab (1962) argued that expertise in teaching requires both knowledge of a content of a domain and knowledge about the epistemology of that domain. Teachers develop the necessary capability of transforming subject into teachable content only when they know how the disciplinary knowledge is structured. Numerous studies (e.g. Lampert, 1990; Shulman, 1987) have illustrated the centrality of disciplinary knowledge in good teaching. The challenge facing teacher education is that teachers in general have had little exposure to issues of chemical knowledge beyond content knowledge (Erduran, Aduriz-Bravo, & Mamlok-Naaman, 2007). Future teacher education, then, should acknowledge the contributions of philosophy of chemistry in chemistry education in an effort to instil in teachers an understanding of other aspects of chemical knowledge than content knowledge. It is likely that promotion of epistemological, linguistic and ethical aspects of chemistry would contribute to the strengthening of teacher's "subject matter knowledge" as well as "pedagogical content knowledge" (Shulman, 1987).

Conclusions

In this paper, I have argued that philosophy of chemistry holds the potential to contribute to chemical education research through studies on such aspects of chemistry as epistemology, linguistics and ethics. This approach builds on the arguments offered by Scerri (2003) that philosophical reflections on grand themes such as realism, objectivism and behaviourism would clarify confusion in chemical education research. Future chemical education research will benefit from not only philosophical but also sociological, anthropological as well as psychological investigations into the chemical sciences. Afterall, chemistry classrooms are complex environments where all of these fields coincide. If we, as chemical educators, want to instil in learners what chemistry is about, how chemists think and operate, our current narrow approaches in terms of subject-matter knowledge is no longer good enough. Interdisciplinary inquiries into chemistry learning and teaching hold the potential to improve chemical education.

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