Chemistry Education Research and Practice

EDITORIAL

View Article Online
View Journal | View Issue

Cite this: *Chem. Educ. Res. Pract.*, 2016, **17**, 434

Language and the teaching and learning of chemistry

Silvija Markic*[a] and Peter E. Childs[b]

DOI: 10.1039/c6rp90006b

www.rsc.org/cerp

"*Science without literacy is like a ship without a sail. [. . .] So just as it is impossible to construct a house without a roof, it is impossible to build understanding of science without exploring how the multiple languages of science are used to construct meaning*" (Osborne, 2002, p. 206).

The importance of language for learning chemistry has been known for a long time and has been discussed recently in several places (*e.g.*, Taber, 2015). However, its relevance and presence in science education research and in the teaching and learning of chemistry change. In the past, school and university populations were more uniform in language and culture, and at university level a high degree of literacy in the language of instruction could be expected. In teaching chemistry, the main linguistic focus was seen only as the learning of nomenclature and new technical terms, and this was seen mainly in terms of memory work (Fang, 2006). We are now much more aware that the role of language in the teaching and learning of chemistry is more diverse and challenging, especially with the changing nature and diversity of the student population in language, culture and ability (*e.g.*, Markic *et al.*, 2013; Childs *et al.*, 2015).

Lee and Fradd (1998) and Lee (2005) showed that a lack of linguistic skills and unfamiliarity in asking questions, investigating, and reporting results using science language, can demotivate students towards their science lessons. However, it is exactly those activities which support inquiry-based learning, support students' language development and pursue the aims of Scientific Literacy. It is essential for students' knowledge of chemistry that they can comprehend and explain in clear language fundamental science concepts. There are several activities that take place in the classroom – such as reading, writing, listening, and speaking – which also require different dimensions of language use and reflect the importance of communication as a scientific skill. For example, during problem solving students read and write using scientific language: written text is read and spoken language is used to communicate the path taken from the initial state to the goal (Lemke, 1989).

Thus, the promotion of linguistic skills is one of the key objectives of chemistry teaching. It is and should be one of the central aims of teaching and learning in chemistry education. It is important for students to learn the language of chemistry with its technical terms, formulae, and patterns of argumentation. The more limited students' skills are in understanding and using the language of chemistry, the more difficulties they will have in using teaching and learning materials in their future chemistry education and understanding and expressing scientific concepts. Raising their scientific language ability will help in developing their understanding and increase their "*ability to observe, to think logically, and to communicate effectively*" (DES, 1999).

The language of chemistry is not the only language that is spoken in chemistry classrooms or university seminars. To teach the language of chemistry, teachers use the language spoken in the country they are working in. Furthermore, there are even more languages and levels of language proficiency among those present in the classroom during a single lesson. Some of those dimensions are verbal and some non-verbal (see Fig. 1).

Usually the appearance of the topic of language in science education research, but also in education research in general, depends on recognition of changes in society and in the movement of peoples and events in world history. For example, in the 1970s a lot of Italian, Balkan and Turkish families moved to Germany for new jobs and searching for better lives. These were mainly men working in construction and industry and women and children who were staying at home and attending school. The vast majority kept their native language as an everyday language. For some years the influence of such a movement was not strongly noticeable. It appeared again in the middle of 1990s because of the civil war in the Balkan countries. Now about 20 years later refugees from all over the world are coming to Germany. However, the influx of migrants is true for most of the western European countries. For example,

[a] *Institute of Didactics of Science Education – University of Bremen, Germany. E-mail: smarkic@uni-bremen.debbb*
[b] *University of Limerick, Ireland*

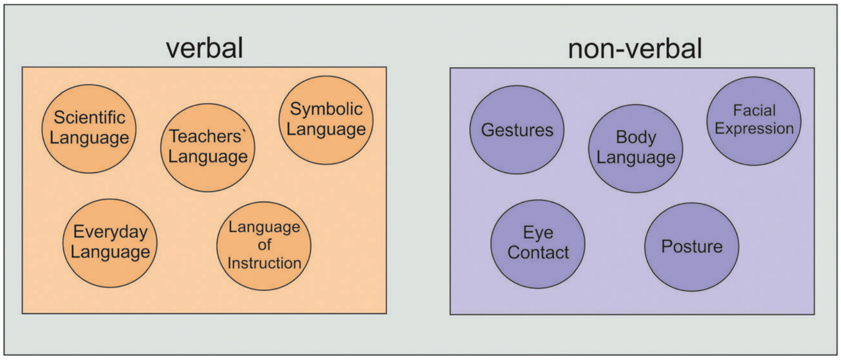

Fig. 1 Languages "spoken" while teaching and learning chemistry.

in Ireland over 12% of the population is non-national and in some schools the percentage is much higher. Thus, heterogeneity in the school and university contexts is high and we can no longer assume high levels of literacy in the national language. The problems of second-language learners appeared first in schools (primary and secondary) but it is now a significant problem at university level education across Europe.

However, all of the students – independent of their everyday language and native language – have the language of chemistry in common in chemistry lessons. Thus, in this field of chemistry education research we are not talking about different languages, we are taking about – as the authors like to call it – '*chemish*' – the language of chemistry, which is itself a multifaceted language.

The characteristics of '*Chemish*'

"*Science does not speak of the world in the language of words alone, and in many cases it simply cannot do so. The natural language of science is a synergistic integration of words, diagrams, pictures, graphs, maps, equations, tables, charts, and other forms of visual mathematical expression*" (Lemke, 1998).

As with every language in the world, *chemish* also has own characteristic and rules. Wellington and Osborne (2001, p. 19) highlighted the fact that "*one of the important features of science is the richness of the words and terms it uses*". Further Lemke (1998) has pointed out the diversity of the breadth of language in science.

The alphabet in *chemish* is expressed in the symbols for the chemical elements, words are the formulae of chemical substances and sentences and syntax are chemical equations and the rules of chemical combination. However, an alternative view by Liu and Taber, in this issue identifies letters as arbitrary symbols in a language, so that the symbols/names of elements are not letters but words and the formulae/names of compounds are word groups. Scientific literature is written in a different way to the novel or narrative literature. When someone does not understand one word or even a whole sentence in a page of a Harry Potter book, for example, it still makes sense and you can understand the story in the book. But when you do not understand a few words or even a single word on a page of chemistry text, it may not make sense and may lead to misunderstanding the concept. The reason is that in chemistry texts, the written sentences are much shorter and filled with information, and often include logical connectives. Recently talking to chemistry teachers on this topic, we came to the conclusion that it does not really make sense to ask students to underline the important parts of the text, since for them, all of it is important to understand the concept. Since the pioneering work of Gardner (1972a, 1972b) and later Cassels and Johnstone (1980, 1983, 1985), there has been a recognition that non-technical words used in science with a different meaning to their use in everyday language, can be as big a problem in understanding technical texts as the specific technical vocabulary. In addition, chemistry carries the burden of a complex and universal symbolic language, which is independent of the national language, but is in itself a language of its own, akin to mathematics and its symbolic language. A chemist can 'read' and understand the formulae and equations and diagrams in a paper or book written in a foreign language, while not understanding the written text.

Difficulties in learning *Chemisch*

It is this uniqueness of the language of chemistry that causes difficulties in chemistry teaching and learning. Wellington and Osborne (2001, p. 2) claimed that "*Language is a major barrier (if not the major barrier) to most students in learning science*".

The greatest issue is that *chemish* differs in several areas from the students' everyday language. In the language of chemistry (Fig. 2; see Childs *et al.*, 2015, and Childs and Ryan, in press):

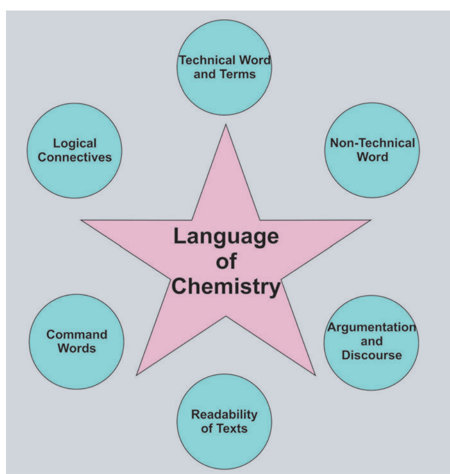

Fig. 2 Dimensions of learning the language of chemistry.

• The majority of words stem from Greek or Latin, which are languages which are no longer familiar to the majority of the students, *e.g.*, synthesis, electrolysis; ...

• There are double meaning words – words having different meaning from their everyday use when used in a specific scientific context, *e.g.* matter, solution, element;

• There is a technical and specialised vocabulary of science (*e.g.* names of laboratory equipment, nomenclature), rarely met in everyday life, which is like learning a foreign language;

• There is a complex symbolic language of chemistry;

• There is frequent use of mathematics, often connected to abstractions (*e.g.* equations, operations), with another specialist vocabulary and symbolic language;

• Students are asked for the interpretation and labelling of graphs, diagrams, flow charts *etc.* within a scientific context; and

• There is specific logical argumentation patterns in scientific arguing and writing, *e.g.* in a laboratory-report or scientific paper.

Laszlo (2013) and others have suggested teaching the language of chemistry as a language in its own right. Laszlo (2013, p. 1682) stated that "...*chemistry teachers are linguistic guides, they are interpreters, they teach their students how to craft well-formed chemical sentences*". However, chemistry teachers are mainly not aware of the importance of explicitly teaching and learning the language of chemistry (*e.g.*, Ryan and Childs, 2013). Most teachers see language and the subject content as dichotomous and do not see their role as science teachers in also teaching language (Markic, 2014; 2015). Thus, in the first instance it is important that chemistry teachers are aware of the complexities which students are confronted with when learning the language of chemistry. The teacher is an expert who has mastered the languages of chemistry and often does not recognise or has forgotten his/her own problems in learning the language. Secondary teachers are probably more aware of the issues than university level teachers, who tend to assume that their students have already mastered the basic language of chemistry at school.

The main aim of science education is to assist students in utilising the multiple languages of science to construct and interpret meaning. From a linguistic and semiotic perspective, in science education the concern is not solely in ensuring that students understand the concept but also that they can move back and forth between the different representations – verbal, symbolic, diagrammatic – and that they can begin to recognize, use and interpret the equivalencies between these forms (Osborne, 2002). Lemke (1998) has stated that complete understanding of a concept only occurs when each of the facets of the language, which represent that concept, are utilised in an integrated and overlapping manner. In light of such linguistic complexity, it is hardly a surprise that many students, at all levels of the educational system, find it difficult to fully understand scientific concepts.

Contribution of this special issue to the topic

The teaching and learning of the language of chemistry is a problem that students face at both secondary and tertiary level. Thus, also the papers in this special issue focus on different levels and also deal with different aspects of the use of language in teaching and learning chemistry.

Liu and Taber focus on the symbolic representations of chemistry, and identify and analyse them as a source of learning difficulties on the one side but also essential for the language of chemistry on the other.

Canan and Kerman evaluate students' understanding and the usage of *chemish* (focusing on names) in different French schools. Unfortunately, they concluded that even after two years of teaching the language of chemistry, students still have great difficulties understanding chemical concepts. In this study the students were not able to understand formulae in the context of chemistry, *e.g.* chemical equations.

Similarly, Vladušić, Bucat and Ožić evaluated the understanding of undergraduate and graduate chemistry students' understanding of words and symbols at the University of Split, Croatia. Astonishingly – since the students were at the tertiary level and chose chemistry as their major subject – the participants of this study did not understand completely the meaning of technical words, symbolic representations and also everyday words which are used in chemistry as well. Also concentrating their research on tertiary level chemistry students, Haglund, Andersson and Elmgren as well as Nyachwaya and Evans, Pabuccu and Erduran focused their separate studies on single concepts and so on specific technical terms in science education (namely, entropy; acid–base neutralization and conductiometry; gas behaviour). In their study with Chemistry Engineering students, Haglund *et al.* discuss the problem of students' connection of three chemistry concepts and weak connections between students' problem-solving skills and their conceptual understanding of entropy. Nyachwaya and Evans showed that their college-level, general chemistry students could not transfer knowledge to a new context, while applying acid–base neutralization ideas to the context of conductiometry. The study of Pabuccu and Erduran focuses on argumentation in chemistry learning and it tries to understand how to develop students' engagement in the argumentation process, how to enhance the quality of students' argumentation, and how to improve their conceptual understanding of gas behaviors.

From all these studies we can conclude that more attention needs to be given in teaching *chemish* in our classes at university. However, an even stronger conclusion is that more work needs to be done to make teachers and educators more aware of, and more sensitive to, this problem, and in supporting them to develop teaching and learning tools for dealing with specific technical language (Ryan, 2015).

To close this gap, Yuriev, Capuano and Short focused their research on methods for supporting students in learning scientific language. They used crossword puzzles for chemistry education as a specific method for mastering the language of chemistry, and in particular, the definition of terms and concepts. Furthermore, Repice *et al.* suggest in their paper that the collaboration between the students during work in peer-led small groups is a possible method to improve language skills. This video study shows that students talk their way through the problems; taking turns, questioning and explaining, building on one another's ideas, and thus regulating and improving their own and their group's learning through collaboration. Also Putra and Tong focus on the development of teaching and learning methods and suggest one which can be used in secondary school chemistry classes – but which we suggest may also be suitable for use in tertiary education as well. In this case study with one teacher the authors describe in detail the lesson plan and the PRO (Principle–Reasoning–Outcomes) structure for supporting students' writing skills in constructing scientific explanations.

Focusing on *chemish*, Robson, Bruce, Coffer and Rees focus on the aspect of writing technical papers. In their paper the authors describe a writing workshop at the University of Durham. The project started some years ago and the authors describe it as a ''unique perspective on the interplay between language and scientific literacy''.

Current and Kowalske focus on laboratory work, looking at the instructional practices of chemistry graduate teaching assistants in the undergraduate laboratory.

However, not all of the students in our classes, lecturs, seminars and labs are proficient in the language spoken in the classroom. Focusing not only on the language of chemistry but also different native languages, Cink and Song report on a study of four community college students with diverse ethno-linguistic backgrounds. One of the main results is that the participants' prior English learning experiences and classroom culture shaped their appropriation of scientific vocabulary and it was found that the participants' appropriation of chemistry language was deeply related to how they incorporated scientific culture into their everyday culture. This study shows not only the great importance of taking account of students' native language but also of their cultural background.

Finally, a facet of language in the chemistry classroom which is under represented in chemistry education research, is the use of gestures. In her paper, Abels discusses the importance of gestures in chemistry teaching and learning and presents a study on chemistry teachers' usage of gesture in a teacher–student-discourse.

Further research needed

Surveying the research presented in this special issue, we can conclude that a lot of research is being done in various areas but more needs to be done in these areas:

– Diagnosing the linguistic skills of students and making allowance for them as well as the CPD in this field (*e.g.* Tolsdorf and Markic, in press)

– Further development of language-sensitive teaching materials for heterogeneous student populations (particularly at second level) (*e.g.*, Markic, 2012);

– Connection of language to culture (Mamlok–Naaman *et al.*, 2015);

– Development of a teacher training programme to handle the language issues (Ryan and Childs, 2013);

– Development of teachers' pedagogical language knowledge in this area (Markic, 2013);

– Focusing on language in tertiary level classes, with increasing diversity in language, culture and ability;

– Research on and development of materials for developing students' writing and reading skills in chemistry classes (*e.g.*, by using digital media).

In looking at any area of chemistry education research one can take a more theoretical, abstract approach (*e.g.* in this case from the angle of linguistics or semiotics) or one can approach it from a more pragmatic, practical and applied direction (*e.g.* how does this help with everyday issues?). Often the more theoretical approach is of little direct use in the classroom and lecture room, although it should inform the way language is used, as it is often seen as too far removed from the day-to-day concerns of the teacher or lecturer. One of the major challenges of chemical education research is to translate theoretical and abstract research into a form that is intelligible and useful to practitioners. The emphasis in the papers in this issue is on research applied to practice, and thus we hope that the various studies reported in this issue will be of direct use to practitioners: those who are involved in teaching chemistry, whether at school or university level. Even then there is the challenge of making teachers and lecturers aware of what research is being done in the area and helping them to apply the findings. We hope that if you find these articles useful that you will bring them to the attention of your colleagues.

We would like to thank all the authors for their contribution to this special issue, and hope that the papers will provide useful ideas and stimulate further research and development in this important area.

References

Cassels J. R. T. and Johnstone A. H., (1980), *Understanding of non-technical words in science*, London: Royal Society of Chemistry.

Cassels J. R. T. and Johnstone A. H., (1983), Meaning of the words and the teaching in Chemistry, *Educ. Chem.*, **20**, 10–11.

Cassels J. R. T. and Johnstone A. H., (1985), *Words that matter in science*, London: Royal Society of Chemistry.

Childs P. E. and Ryan M., (in press), Strategies for teaching the language of science, in Markic S. and Abels S. (ed.), *Science Education towards Inclusion*, New York: Nova Publishing.

Childs P. E., Markic S. and Ryan M., (2015), The role of language in the teaching and learning of Chemistry, in Garcia-Martinez J. and Serrano-Torregrosa E. (ed.), *Chemistry Education: Best Practice, Innovative Strategies and New Technologies*, Weinheim: Wiley-VCH, pp. 421–446.

DES – Department of Education and Science, (1999), *Leaving certificate physics syllabus*, Dublin: The Stationary Office.

Fang Z., (2006), The language demands of science reading in middle school, *Int. J. Sci. Educ.*, **28**, 491–520.

Gardner P. L., (1972a), Difficulties with non-technical vocabulary amongst junior secondary school students: the words in science project, *Res. Sci. Educ.*, **2**(1), 58–81.

Gardner P. L., (1972b), *Words in science*, Melbourne: Australian Science Education Project.

Laszlo P., (2013), Towards teaching chemistry as a language, *Sci. Educ.*, **22**, 1669–1706.

Lee O., (2005), Science education with English language learners: synthesis and research agenda, *Rev. Educ. Res.*, **75**, 491–530.

Lee O. and Fradd S. H., (1998), Science for all, including students from non-English language backgrounds, *Educ. Res.*, **27**, 12–21.

Lemke J., (1989), Making test talk, *Theory into Practice*, **28**, 136–141.

Lemke J. L., (1998), Teaching All the Languages of Science: words, symbols, images and actions, available online, http://academic.brooklyn.cuny.edu/education/jlemke/papers/barcelon.htm, accessed on 08 June 2016.

Mamlok-Naaman R., Abels S. and Markic S., (2015), Learning about relevance concerning cultural and gender differences in chemistry education, in Eilks I. and Hofstein A. (ed.), *Relevant chemistry education – from theory to practice*, Rotterdam: Sense, pp. 219–240.

Markic S., (2012), Lesson plans for students language heterogeneity while learning science, in Markic S., di Fuccia D., Eilks I. and Ralle B. (ed.), *Heterogeneity and Cultural Diversity in Science Education and Science Education Research*, Aachen: Shaker, pp. 41–52.

Markic S., (2013), Science teachers' PCK about teaching and learning of scientific language in science classes, in Constantinou C. P., Papadouris N. and Hadjigeorgiou A. (ed.), *Science Education Research For Evidence-based Teaching and Coherence in Learning – Strand 12*, Nicosia, Cyprus: ESERA, pp. 103–108.

Markic S., (2014), Heterogeneity? – Challenge and/or opportunity in science education? *Sisyphus – J. Educ.*, **2**(2), 32–47.

Markic S., (2015), Chemistry Teachers' Attitudes and Needs when Dealing with Linguistic Heterogeneity in the Classroom, in Kahveci M. and Ogill M. (ed.), *Affective Dimensions in Chemistry Education*, Heidelberg: Springer, pp. 279–296.

Markic S., Broggy J. and Childs P., (2013), How to deal with linguistic issues in the chemistry classroom, in Eilks I. and Hofstein A. (ed.), *Teaching Chemistry – A Studybook*, Rotterdam: Sense, pp. 127–152.

Osborne J., (2002), Science without literacy: a ship without a sail? *Cambridge J. Educ.*, **32**(2), 203–218.

Ryan M., (2015), *An investigation into the role of language in science education at junior cycle level in Ireland*, unpublished PhD thesis, University of Limerick, Limerick.

Ryan M. and Childs P. E., (2013), Irish science teacher's views on linguistic diversity, in Constantinou C. P., Papadouris N. and Hadjigeorgiou A. (ed.), *Science Education Research For Evidence-based Teaching and Coherence in Learning – Strand 12*, Nicosia, Cyprus: ESERA, pp. 47–54.

Taber K. S., (2015), Exploring the language(s) of chemistry education, *Chem. Educ. Res. Pract.*, **16**, 193–197.

Tolsdorf Y. and Markic S., (in press), Dealing language in science classrooms – diagnosing students' lingustic skills, in Markic S. and Abels S. (ed.), *Science Education towards Inclusion*, New York: Nova Publishing.

Wellington J. and Osborne J., (2001), *Language and literacy and science education*, Buckingham: Open University Press.

