Chemistry Education Research and Practice

PAPER

Cite this: *Chem. Educ. Res. Pract.*, 2016, **17**, 474

Understanding of words and symbols by chemistry university students in Croatia

Roko Vladušić,*[a] Robert Bucat[b] and Mia Ožić[a]

This article reports on a study conducted in Croatia on students' understanding of scientific words and representations, as well as everyday words used in chemistry teaching. A total of 82 undergraduate chemistry students and 36 pre-service chemistry teachers from the Faculty of Science, University of Split, were involved. Students' understanding of language was probed using a diagnostic instrument with various types of tasks: creation of a scientifically sensible sentence using the key word provided without context; explanation of the meaning of a word provided in a contextual sentence; selection of the appropriate usage of a term from multiple-choice options; explanation of the meaning of a word provided without context. With every kind of task, evidence of inadequate understanding of many terms and symbols was found. Accordingly, it cannot be presumed that students in Croatia, either undergraduates or graduates, understand well the meanings of scientific words, symbolic representations or everyday words that are used in teaching and learning chemistry. There are considerable differences in the extent of understanding, from word to word, and symbol to symbol. Some of the findings are in common with other studies conducted in English-speaking countries, and some are particular to the Croatian language – especially due to students' confusion in the cases of similar sounding words with different meanings, and the different meanings of words in the everyday and science contexts. Recommendations are made for teaching that involves specific attention to learning about the language associated with topics, through reflective discussion and in formative assessments. Issues of knowledge transfer from research to teachers' pedagogical content knowledge, as well as considerations for further research, are discussed.

Received 30th January 2016,
Accepted 5th April 2016

DOI: 10.1039/c6rp00037a

www.rsc.org/cerp

Introduction

This paper reports on a study of tertiary students' understanding of various common terms and symbols used in chemistry teaching and learning in Croatia. The findings have potential to enrich chemistry teachers' pedagogical content knowledge.

Shulman (1986) suggested that we should distinguish three categories of content knowledge: (a) subject matter content knowledge, (b) pedagogical content knowledge (PCK) and (c) curricular knowledge. PCK, a transformation of subject matter content knowledge for teaching (Shulman, 1987), is of particular interest to the research reported here.

The concept of PCK has been further developed by numerous science educators and has been conceptualised in a variety of ways. We follow the work of Magnusson *et al.* (1999), who conceptualised PCK as being comprised of five discrete components: (1) orientation towards science teaching (knowledge of and about the subject, beliefs about it, and how to teach it), (2) knowledge and beliefs about science curriculum (what and when to teach it), (3) knowledge of students' understanding of science, (4) knowledge of assessment in science (why, what, and how to assess it), and (5) knowledge of instructional strategies.

We are especially interested in the third component: knowledge of students' understanding of science, and particularly in the meanings that students attribute to the language forms (words and symbolic representations) used in chemistry teaching.

Familiarisation with the language of science necessarily occurs more or less simultaneously with learning the science content. Each is inextricably linked to the other, reversibly providing both opportunities for development and potential limitations. The view has been expressed that language is perhaps a bigger barrier to learning science than is the content itself (Gabel, 1999; Yong, 2003). Pyburn *et al.* (2013) have demonstrated that there is a correlation between language comprehension ability and general chemistry performance, and recommended that instruction in general chemistry should include the development of language comprehension skills.

Upon reflection, it seems obvious that we should pay attention to language precursors to understand a topic as well as to content precursors. In an editorial forerunner to this theme issue of CERP, Taber (2015) suggested that experienced chemists, when in instructional situations, may take for granted the language skills

[a] *The University of Split, Faculty of Science, Croatia. E-mail: vladusic@pmfst.hr*
[b] *The University of Western Australia, School of Biomedical and Chemical Sciences, Australia*

of the students and ignore the diligence that this problem demands. He pertinently quotes Laszlo (2002, p. 117) in relation to understanding symbolic language:

Out of laziness they are likely to fall back on the technical jargon they are used to. Our electron-pushing jargon of reaction mechanisms is a lovely means for chatting among ourselves. It is an economical shorthand. To extend its use from the laboratory to the classroom, when we teach non-majors, is to force linguistically incompetent speakers to master a slang, when they are unable to express themselves in the parent language.

A pool of research evidence related to particularities of students' understanding of language has grown rapidly in recent years. Probably the first significant research to draw attention to the issue of poor understanding of vocabulary was that of Gardner (1972). He reported about students' understanding of important non-technical words used in science teaching. He found that many words on which science teachers highly depend, like *associate*, *average*, *contrast*, *simultaneous* and *theory*, were not accessible to the pupils. A word list organized on the basis of levels of difficulty was compiled.

A similar research study, based mostly on the words investigated by Gardner, was conducted in Britain as part of the Chemical Society project (1977–1979). To avoid the influence of context on the meanings, the understanding of each word was investigated with several questions. About 23 000 pupils and faculty students were involved. With respect to non-technical words that may cause difficulties to pupils and students, Cassels and Johnstone (1980) suggested that the various connotations of words, words that sound similar, and words with similar meanings should be explicitly discussed with students when appropriate. They further recommended that words need to be explained in context, and that pupils should be encouraged to express the meanings of new words in words of their own.

Cassels and Johnstone (1980) noted that words used in non-scientific contexts generally appeared to be better understood than their use in scientific contexts.

Searching for a clearer indication of how teachers can help pupils to make connections between new and existing vocabulary, Cassels and Johnstone (1985) used 95 of "the most difficult words" in multiple choice questions in (i) an everyday context, (ii) a scientific context, and (iii) the virtual absence of context. Very few words were well understood. In many cases pupils assumed the opposite meaning to that of the key word. Wellington and Osborne (2001) found a general, but not universal, progression in understanding from the first to the sixth form.

Using similar questions to Cassels and Johnstone (1985), Pickersgill and Lock (1991) tested the understanding of some non-technical words by students aged 14–15 years, and Marshall *et al.* (1991) conducted a similar study with grade 7 up to first-year university students. In both cases, the general conclusion drawn was that a significant number of students were unfamiliar with the meanings of most words. Both studies provided the lists of words that require special attention. It was found, for example, that *consistent*, *device*, *evacuate*, *exert*, *random and reference* are among "the most difficult" words (Marshall *et al.*, 1991). The problem of antonyms was recognized in both studies.

Marshall *et al.* (1991) reported a tendency of students to confuse words with graphologically or phonetically similar ones; *e.g.*, consistent with *constituent*; *component* with *opponent.* Their results show some progression in the understanding of words from lowest to highest grades, although, again, not universal.

Johnstone and Selepeng (2001) repeated part of the work of Cassels and Johnstone on a small scale, choosing 25 words which a science teacher would probably use on the assumption that the students would understand them. The students were 15–16 years old. They identified similar problems to those found in the earlier study.

Farrell and Ventura (1998) investigated whether the understanding of words in higher science education is a problem amongst Maltese students. In particular, they investigated the differences between students' *perceived* comprehension (what they claimed to understand) and *actual* comprehension (what they really understood). The study was conducted on a sample of 306 Advanced-level physics students, 17 years old on average. They investigated the understanding of 75 of the most frequently used words in Physics A-level education, of which 50 are non-technical (*e.g. excess*, *related* and *random*) and 25 are technical (*e.g. mole*, *acceleration* and *power*). Comprehension was considered inadequate in the cases of 31 non-technical words, and all of the technical words. In most cases, the percentage of students who knew the meaning of a word was significantly lower than the percentage of those who claimed to know. That was so for all technical words.

The studies of Lynch *et al.* (1979) and Meyerson *et al.* (1991) focused particularly on the understanding of technical words. Lynch *et al.* (1979) examined the acquisition of the understanding of a pool of technical words associated with the theme "*the nature of matter*". The study involved 1635 high school students (12–16 years). In multiple choice items, the students were asked to recognise simple definitions of 16 concept words like *mass*, *element*, *atom*, *electron* or *mixture.* The findings demonstrate problems with the understanding of the key words. For example, more than 30% of the oldest students did not choose the appropriate definition for *solid*. The definition of the *electron* was not recognised by 60% of them.

Meyerson *et al.* (1991) found some progression in science vocabulary knowledge from third to fifth-grade students. However, problems in science vocabulary usage were recognized, especially with words that have multiple meanings. Many multiple-meaning words were given their non-scientific meanings by some students. For example, several third graders defined *mass* as *something at a church*.

The particular challenge presented by chemistry vocabulary that has both scientific and everyday meanings has been the subject of study by many scholars, such as Cassels and Johnstone (1980, 1985), Brown and Spang (2008), Snow (2010), Jasien (2010, 2011), and Brown (2011). Song and Carheden (2014) undertook a qualitative study that investigated how college students understand selected dual meaning vocabulary (DMV) words before and after chemistry instruction. They found that (i) before instruction, most students defined a DMV term with its everyday meaning, (ii) after instruction, retention of the scientific meanings of DMV words was poor, and (iii) lack of retention of scientific meanings was attributed to infrequent usage, study habits, and ignorance of other scientific vocabulary terms. The last of these three factors suggests that a poor understanding of scientific vocabulary, at least in the case of DMV terms, can have a multiplying effect.

The use of symbolism in chemistry communication has its own challenges for students. The complexity of the interpretation of symbolic language forms has recently been analysed in respect of structural representations by Bucat and Mocerino (2009), and in relation to chemical formulae and equations by Taber (2009). The dependence of adequate interpretation of chemical symbolism on the awareness of the chemistry triplet (Johnstone, 1982, 1991) was discussed by Talanquer (2011) and Taber (2013). Through two case studies of classroom discourse, Stieff *et al.* (2013) demonstrated that teachers and students are biased to reason about chemistry phenomena from different levels. Students often displayed ''levels of confusion'': despite instruction, they confuse features applicable to one level with those of other levels.

Marais and Jordaan (2000) found that many first-year chemistry students at the tertiary level were unable to identify correct meanings of various very basic components of chemical equations (such as $\Delta H > 0$, $\rightarrow$, $[NO_2]$, and $2NO_2$). Analysis suggests a large number of steps involving the comprehension of symbols that students must go through in order to answer a seemingly simple question about the perturbation of a gaseous equilibrium system. The authors comment, in relation to examination questions: ''... how can we expect our students to answer our questions if it is a fundamental truth that one can only hope to answer a question correctly if one understands the question completely. Understanding the question implies understanding the language (words and symbols) used in formulating the question.''

Taskin and Bernholt (2014) have comprehensively reviewed numerous research reports on students' understanding of chemical formulas and their use. They identified three categories of students' problems and difficulties, of which the first and third are relevant to the study reported here: language-based problems, problems due to conceptual understanding, and problems due to the inadequate selection and interpretation of formulae.

The literature reviewed provides evidence that both the technical and non-technical vocabulary of chemistry pose problems for students, at least in the English language. However, no research has been reported concerning language issues particular to the Croatian chemistry education system. It is conceivable that aspects of the Croatian culture, as well as characteristics of both everyday and scientific terms in the Croatian language may give rise to peculiar issues of language comprehension. The implications of this may be applicable to neighbouring nations whose languages are closely related to Croatian.

As part of PCK, it is important to know what particular language items cause problems for our students. For example, it is PCK to realise that the term *dispersion force* may provide some confusion for chemistry students because in everyday usage the term *dispersion means* ''to spread out'' (Bucat, 2004) or that ''sharing'' of electrons is a metaphorical, rather than technical, description of the bond (Taber, 2002). Teaching about bonding, it is important to know how our students see *interactions* and how well they understand the term *electronegativity*. Again, it is PCK to recognize the problems and to provide useful strategies for their avoidance or resolution.

With the aim of increasing our PCK related to language issues in chemistry teaching in the Croatian language, this study was directed by the following research questions:

How well do Croatian (i) undergraduate chemistry students and (ii) graduate students (pre-service chemistry teachers) understand:

(1) science words and symbolic representations that are used in teaching and learning chemistry?

(2) everyday words that are used in teaching and learning chemistry?

The research reported here can be described as an exploratory study in the sense that its primary intention is to investigate the extent of comprehension issues associated with instruction in the Croatian language, rather than to analyse the origins of problems that were found. Neither is the purpose to make comparisons between findings in Croatia and those in other systems, nor between population samples within Croatia.

It was decided to conduct this study at the tertiary level of education because the author directly involved in the conduct of the research (R.V.) is a lecturer in chemistry and chemistry education at this level. Apart from the convenience of having access to his own students for the purpose, he was motivated to increase his awareness of how students from his faculty comprehend the meanings of various language items used in chemistry, often taken for granted. In essence, this study can be seen as the first component of an action research project as he modifies his teaching in the future, in response to the findings, and studies the effect of having done so. A further motivation, with widespread implication for the future, is related to the fact that most of the students involved in the study will attain qualification as chemistry teachers upon graduation. Through participation in the research, confrontation with the findings, and their explicit discussion, it can be expected that they too will become more aware of differences between their presumptions and the reality in terms of language comprehension. It can be further expected that these students will take into account their newly acquired language-related PCK in their own classrooms in future.

Ethical considerations

The research reported here was administered by the Faculty of Science, University of Split, as part of a wider investigation carried out as a requirement for the PhD degree. Everything was performed in compliance with the relevant laws and institutional guidelines. The approval for the research was provided by the Ethics Committee of the Faculty of Science, University of Split, Croatia (classification mark 641-01/13-01/00009). The surveys were completed voluntarily and anonymously.

Methodology

Eighty-two undergraduate chemistry students and 36 graduate, pre-service chemistry teachers from the Faculty of Science, University of Split, were involved in this research. A large majority of undergraduates were enrolled in the Chemistry and Biology study program.

A diagnostic pen-and-paper instrument (Appendix) was designed to examine, in a variety of ways, students' understanding of selected language objects used in the teaching of chemistry. The objects include both scientific and non-scientific Croatian words, as well as a variety of symbolic representations. The instrument consists of four blocks of tasks, of which blocks 1, 2, and 4 are relevant to the research questions of this study, and the findings reported here. The tasks in block 3 fall outside the scope of this research.

Just as we recognise that language as the medium of instruction has potential as a confounding factor in teaching and learning (Louisa *et al.*, 1989), so too we must accept that language as a medium of evaluating understanding has potential for mis-diagnosis. This has been demonstrated by Clerk and Rutherford (2000) and must be recognised as a limiting factor of the accuracy of judgements made about students' understanding. This is why a variety of diagnostic tasks were used to achieve a degree of confirmation of findings, even though no language terms were investigated with more than one kind of task.

Although not a primary purpose of this study, a Chi-square test was used to assess whether the differences between success rates of graduates and undergraduates for each term, in each block, are statistically significant. Also, the Chi-square test was used to determine whether there is a significant difference between self-confidence responses of undergraduate and graduate students.

First block of tasks

The first block consists of two sets of tasks, A and B. In part A, students were given five terms that are commonly used in chemistry, with no context provided. In each case, they were asked to create a sensible sentence that includes the key term. The objective was to see if students could use the term in a scientifically sensible way – although we neglected to include the term ''scientifically'' in the task definition. There was no expectation that the students would define the term, or explain its meaning. In fact, in order to allow the students a free response, we avoided wording such as ''Define ....'' and ''Explain the meaning of ....''. We also looked to see in what context students chose to use each word.

Each response was evaluated and allocated to one of the self-evident categories ''successful'', ''partially successful'', or ''unsuccessful''. Evaluation was conducted independently by two of the authors (R.V. and M.O.). In the event of an unresolvable difference, a judgement was made by an independent colleague.

In part B, students were asked to express the meaning of six terms (*force*, *formula*, *relative*, *crystal*, *radius*, and *spin*) that are commonly used in science. Each word was provided in a sentence with a scientific context. Unlike the other terms, the word *relative* is not a term for a science concept, although it is frequently used in science contexts. The goal was to see if students could explain the meaning of each term in the context of the sentence. Categorisation of responses as ''correct'', ''partially correct'', or ''incorrect'' was performed as in part A.

Second block of tasks

The tasks in this section were designed to explore students' understanding of the meanings of everyday words used in teaching chemistry in Croatia. In this part of the questionnaire, students were presented with multiple choice items for each of the twenty words. Unlike the tasks in Block 1, in which students were required to either use a key word or explain its meaning, this section is a test of students' abilities to recognise the appropriate use of key words. Each of the items consists of four sentences in which one of the key words is used. The objective was to find if students could recognise the sentence that best portrays the meaning of each word. This block of tasks is shown in the Appendix.

This part of the questionnaire is based on the work of Johnstone and Selepeng (2001). Most of the words selected for investigation are widely used in everyday life in Croatia and well as in the teaching of chemistry. Choices were designed to suit the Croatian context, and the distracters were designed to seem plausible in the event of students' uncertainty. One common way of achieving this was to design sentences that describe an incorrect property or phenomenon that might seem to be attractive. Another was to design sentences appropriate to words that are similar (in Croatian) to the key word, but which have a different meaning.

Some of the key terms have meanings in both scientific and everyday contexts. The sentences used in the diagnostic instrument test the students' understanding in the everyday context.

Fourth block of tasks

In this section of the instrument, we investigated students' understanding of 20 terms and symbols that are commonly used in chemistry. Students were asked to briefly explain the meanings of the terms and symbols, provided without context. In addition, students were asked to rate, on a scale from 1 (absolutely certain) to 5 (highly uncertain), their self-confidence in the correctness of their answers.

The answers were judged to be ''scientifically correct'', ''partially correct'', or ''incorrect''. The absence of a response was classified as incorrect on the grounds that it demonstrated lack of understanding.

Results and discussion

First block of tasks, part A

Students were assessed on their ability to create sentences in which particular words were used in a scientifically sensible way. The percentages of students whose responses were categorised

Table 1 Degrees of success in using terms to create scientifically sensible sentences. *N*(undergraduates) = 82, *N*(graduates) = 36. The numbers in the "unsuccessful" category include those who did not write a sentence at all

		Undergraduates		Graduates	
		N	%	*N*	%
Coefficient (Koeficijent)	Successful	26	31.7	17	47.2
	Partially	8	9.8	2	5.6
	Unsuccessful	48	58.5	17	47.2
Amount of substance (Množina)	Successful	48	58.5	22	61.1
	Partially	7	8.5	2	5.6
	Unsuccessful	27	32.9	12	33.3
Analysis (Analiza)	Successful	34	41.5	12	33.3
	Partially	7	8.5	1	2.8
	Unsuccessful	41	50.0	23	63.9
Centre of gravity (Težište)	Successful	4	4.9	2	5.6
	Partially	7	8.5	2	5.6
	Unsuccessful	71	86.6	32	88.9
Conformation (Konformacija)	Successful	11	13.4	9	25.0
	Partially	7	8.5	5	13.9
	Unsuccessful	64	78.0	22	61.1

as successful, partially successful, or unsuccessful, are shown in Table 1.

Table 1 shows that many students, both undergraduates and graduates, were not able to create a scientifically sensible sentence using the terms provided without context. The highest success rates (58.5% and 61.1%) were achieved with the term *amount* (of substance), and the lowest (only 4.9% and 6.1%) with *centre of gravity*.

In general, the low success rate was not due to inability to write a sentence using the key words, but failure to write a scientifically sensible sentence. For example, in the case of the word analysis, all but one student wrote sentences. However, of those who were evaluated as unsuccessful or partially successful, 47 wrote sentences that used everyday meanings of the word, rather than its scientific meaning. Examples include:

I was analysing the situation to solve it in an easier way.

An analysis of the economic condition of the country is conducted.

The other terms which were most often used with their everyday meanings were *centre of gravity* and *coefficient* (28 and 22 students, respectively).

With hindsight, it is acknowledged that the students were not specifically asked to write a scientifically sensible sentence, but we consider that the context of the diagnostic instrument would have made this expectation obvious. Perhaps this oversight should be recognised as a limitation on the validity of this section of the instrument, although evidence to the contrary is that only three students wrote sentences in which the term *amount* was used in an everyday sense. The Croatian word for *amount* (*množina*) also means *plural*, or more than one of something, so there was plenty of opportunity for students to devise sentences with everyday meanings. We conclude that characteristics of the terms, rather than the absence of the word "scientifically" in the task, governed whether or not students wrote scientifically sensible sentences.

Other than writing sentences with everyday or trivial meanings, students' responses were classified as unsuccessful because they were scientifically incorrect. For example, *coefficient* was commonly confused with *quotient*; amount (of substance) was sometimes defined as the ratio of mass and molecular mass (rather than relative molecular mass); the term *conformation* was sometimes taken to mean transformation between molecular shapes, or other changes of molecular structure; and resonant structures (of benzene molecules, for example) were considered to be conformations. Students who stated that some organic compounds can have different conformations demonstrated that they did not distinguish between the terms *compound* (which refers to substances) and *molecule* (which refers to particles).

An interesting case that can be applicable only in Croatian (and related languages) is the term *težište*. This is the word for centre of gravity or, in reference to the distribution of bonding electrons in chemistry, centre of mass. A significant number of students confused this term with (or regarded it as synonymous with) *težnja*, meaning aspiration.

Although the values in Table 1 suggest that for all terms except *analysis* a higher percentage of graduates were successful than were undergraduates, in all cases the differences between the success rates of the two groups are not statistically significant at the 5% level.

First block of tasks, part B

Students were asked to express the meaning of the underlined words in each of the six sentences. The results of classification of students' answers, for undergraduates and graduates, are shown in Table 2.

These values indicate that students experience considerable difficulty in the explanation of the meaning of the key terms in the provided contexts. The only term explained successfully by more than 50% of students was *radius*. The term that provided most difficulty was *spin*: only two students gave satisfactory explanations of its meaning. The percentages of students who correctly explained the meanings of the words *formula* (17.1%, 11.1%) and *crystal* (35.4%, 38.9%) were low, especially given that these are commonly used terms.

A finding of considerable significance is that more than three-quarters of both undergraduate and graduate students gave incorrect descriptions of the meaning of the term *relative*. Although this word is not used for a scientific concept, it is very commonly used in science. For example, it is an integral part of the name "relative molecular mass". Furthermore, we might use this word when we compare the magnitudes of a property of different elements (The electronegativity of fluorine is high relative to that of hydrogen), and we frequently use the derived adverb "relatively" (Fluoride ions are relatively small.).

Amongst the incorrect responses we note another issue that is probably specific to the Croatian language. In Croatian, two words (*polumjer* and radius) are commonly used for radius, and two words (*promjer* and *dijametar*) are used for diameter. Confusion among these terms is perhaps the reason that six students wrote "polumjer is half the radius."

Table 2 Percentages of students with correct, partially correct, and incorrect descriptions of the meanings of the terms in the given sentences

		Undergraduates		Graduates	
		n	%	*n*	%
Attractive forces between molecules are called van der Waals forces.	Correct	34	41.5	8	22.2
	Partially	13	15.9	8	22.2
	Incorrect	35	42.7	20	55.6
The formula of starch is not simple.	Correct	14	17.1	4	11.1
	Partially	21	25.6	13	36.1
	Incorrect	48	58.5	19	52.8
Electronegativity is a relative concept.	Correct	15	18.3	8	22.2
	Partially	3	3.7	0	0.0
	Incorrect	64	78.0	28	77.8
A large and beautifully shaped crystal is rarely found in nature.	Correct	29	35.4	14	38.9
	Partially	10	12.2	7	19.4
	Incorrect	43	52.4	15	41.7
Although an atom does not have a definite boundary, we often use a measure known as atomic radius.	Correct	52	63.4	24	66.7
	Partially	6	7.3	3	8.3
	Incorrect	24	29.3	9	25.0
Each orbital can accommodate two electrons of opposite spin.	Correct	2	2.4	0	0.0
	Partially	56	68.3	13	36.1
	Incorrect	24	29.3	23	63.9

The only sentence for which the difference between the percentages of successful graduates and undergraduates is statistically significant is the last: "Each orbital can accommodate two electrons of opposite spin" (χ^2 = 12.837, df = 2, p = 0.002).

Second block of tasks

This multiple-choice section of the instrument is shown in the Appendix. Indications of how well the twenty words of interest in this part of the questionnaire are understood by students are provided by the data in Table 3.

Many students showed reasonable understanding of how several terms are used: these include *donate* (99%, 100% correct), *disintegrate* (88%, 94%), *limit* (86%, 92%), *derivative* (86%, 83%), *elementary* (88%, 83%), and *charge* (83%, 81%). However, it is obvious from these data that many students understand some of these words (variable from word to word) so poorly that they are not able to recognise their correct use. The most poorly understood terms are *carbonization* (41%, 14%), *modification* (29%, 34%), *fraction* (31%, 47%), *percentage* (27%, 42%), and *neutralize* (40%, 42%). In view of how frequently the latter terms are used in chemistry teaching, this is the cause for concern, and something that chemistry teachers need to be aware of.

There are statistically significant differences between the success rates of undergraduate and graduate students only for the terms *carbonization* (χ^2 = 7.607, df = 1, p = 0.006), better understood by undergraduates, and *simultaneously* (χ^2 = 6.860, df = 1, p = 0.009), better understood by graduates.

By way of example, we analyse more deeply the responses to item 7 concerning the term *simultaneous* (in Croatian, simultano). Each of the distractors, and the distribution of student choices are shown in Table 4.

Table 3 Numbers of students who made the correct choice in each multiple-choice item. In each case, the Croatian word used in the instrument is given in parentheses

	Undergraduates		Graduates	
Keywords	*n*	(%)	*n*	(%)
Derivative (derivat)	71	85.5	30	83.3
Modification (modifikacija)	24	29.3	12	34.3
Carbonation (karbonizacija)	32	40.5	5	14.3
Neutralize (neutralizirati)	32	39.5	15	41.7
Limit (ograničenje)	71	85.5	33	91.7
Effect (efekt)	41	50.6	19	52.8
Simultaneously (simultano)	54	69.2	33	91.7
Consistent (konzistentan)	55	70.5	30	83.3
Percentage (postotak)	31	37.4	15	41.7
Disintegrate (dezintegrirati)	70	87.5	34	94.4
Formation (formiranje)	62	75.6	27	75.0
Charge (naboj)	69	83.1	29	80.6
Elementary (elementarno)	73	88.0	30	83.3
Proportion (proporcija)	64	78.1	26	72.2
Planar (planarni)	44	54.3	23	63.9
Faction (frakcija)	26	31.3	16	47.1
Sublimate (sublimirati)	54	65.9	29	80.6
Generalization (generalizacija)	56	70.9	30	83.3
Permanent (permanentni)	41	52.6	16	47.1
Donate (donirati)	81	98.8	36	100.0

From Table 4 we see that the difference between the performances of the undergraduates and graduates is in distractors 1 and 3, perhaps because they understood the term *simultano* (Croatian for *simultaneously*) to mean *similar*, or *similarly*.

In a chemical context, the verb *neutralize* refers to the process in which acid reacts with base. A more universal meaning is the cancellation of a (single) property. In item 4, only 40% of students chose the statement (3) that the side effects of one drug may be neutralized by the use of another drug. A larger percentage of students (43%) chose distractor 1

Table 4 Percentages of undergraduate and graduate students who responded to each of the choices in item 7 concerning the word *simultaneously*

Item 7	Undergraduates		Graduates	
In which sentence is the word **simultaneously** meaningfully used?	*n*	(%)	*n*	(%)
1. Simultaneous behaviour is a characteristic of stick insects – they are so similar to twigs that they are inconspicuous.	13	16.7	2	5.6
2. Just because she's different, her accent sounded simultaneously.	3	3.8	1	2.8
3. Thoroughly studying the face in the mirror, she concluded that the left and right halves do not apply simultaneously.	8	10.3	0	0.0
4. The two explosions were initiated simultaneously so they sounded like one.	54	69.2	33	91.7
Total	78	100.0	36	100.0

Table 5 Percentages of undergraduate and graduate students who responded to each of the choices in item 4 concerning the word *neutralize*

Item 4	Undergraduates		Graduates	
In which sentence is the word **neutralize** used properly?	*n*	(%)	*n*	(%)
1. The salt solution will neutralize the sweet one.	38	46.9	15	41.7
2. My "A" for knowledge will neutralize the "C" for activities.	4	4.9	5	13.9
3. Side effects could be neutralized with new drug.	32	39.5	15	41.7
4. My "A" for activities will neutralize the "C" for knowledge.	7	8.6	1	2.8
Total	81	100.0	36	100.0

which states that a salty solution will neutralize sweetness. These students seem to consider, perhaps in some non-analytical way, that saltiness and sweetness are opposite extremes of the same property.

We might wonder whether poor performance by both undergraduates and graduates on a given term is for different reasons. At least in the case of the term neutralize, this is not significant. We can see this in Table 5 if we add the percentages that respond to distractors 2 and 4 which are very similar.

With regard to item 16, the keyword used in Croatian, *frakcija*, means *faction* (a sub-group of like-minded people) as well as *fraction*, as applied both to mathematics and chemical separations. In all senses there is an obvious common root. The most sensible statement (3), in which the word *frakcija* is used with its meaning as *faction*, was chosen by only 36% of the students. Almost all of the other students selected distractor 1 in the mistaken belief that the Croatian word *frakcija* means *fracture* (in Croatian, *fraktura*). This is another case of confusion between similar sounding terms with different meanings.

In item 9, the keyword is *percentage* (*postotak* in Croatian). The technically correct definition (statement 1) was selected by only 40% of students. Of the others, 47.1% chose distractor 4, which refers to the share of the volume of olives that is oil. The 5% of students who chose statement 2 perhaps were confused between the terms *postotak* (*percentage*) and *prosječni* (average). The success rate in this item may have been influenced by the fact that the given definition of *percentage* (statement 1) is rather sophisticated, and its meaning may have been difficult to interpret.

The term *karbonizacija* in item 3 presents an interesting language issue. Technically, this word translates in English to *carbonization* – the reduction of organic matter to carbon, such as char or charcoal. The everyday meaning attributed to this word, and used in statement 1 of item 3, is taken from the labels on bottles of water enriched in carbon dioxide (carbonated water), which state "karbonizirana voda" (or "gazirana voda"). This may be a misuse of the word *karbonizacija* (or the adjective derived from it) which has now become common. A more correct translation of "carbonated water" would seem to be *karbonirana voda*, although this term is not found in mainstream dictionaries. Perhaps *karbonizirati* has officially come to mean both "carbonize" and "carbonate".

Table 6 Percentages of undergraduate and graduate students who responded to each of the choices in item 3 concerning the Croatian word *karbonizacija*[a]

Item 3	Undergraduates		Graduates	
In which sentence is the word ***karbonizacija*** meaningfully used?	*n*	(%)	*n*	(%)
1. *Karbonizacija* is the process of formation of carbonated water.	32	40.5	5	14.3
2. The *Karbonizacija* of wood was at such scale that the flame engulfed the curtains in the house.	6	7.6	9	25.7
3. *Karbonizacija* of sugar is the basis of production of delicious sugar decorations for wedding cakes.	29	36.7	16	45.7
4. *Karbonizacija* of white flour at high pressure results in glue.	12	15.2	5	14.3
Total	79	100.0	35	100.0

[a] Because there is ambiguity concerning the English meaning of the Croatian term *karbonizacija*, we have kept the Croatian word in the translated distractors.

Table 7 Percentages of undergraduates and graduates who demonstrated the understanding of word-based scientific terms. For each term, the mean value of responses on the Likert scale of self-confidence is listed for both successful and unsuccessful students, at both the graduate and undergraduate levels. On this scale, "1" is highly confident, and "5" is highly uncertain

		Undergraduates				Graduates			
				Self-confidence				Self-confidence	
		n	%	Mean	St. dev.	*n*	%	Mean	St. dev.
Corpuscular (korpuskularno)	Correct	2	2.4	3.50	2.121	5	13.9	2.60	2.191
	Partially	0	0.0	—	—	0	0.0	—	—
	Incorrect	14	17.1	3.57	1.453	11	30.6	3.91	1.044
	No response	66	80.5	—	—	20	55.6	—	—
Mass number (nukleonski broj)	Correct	31	37.8	1.61	1.145	23	63.9	2.00	1.314
	Partially	16	19.5	1.19	0.403	1	2.8	3.00	0.000
	Incorrect	27	32.9	2.00	1.544	10	27.8	2.30	1.252
	No response	8	9.8	—	—	2	5.6	—	—
Propane-1,2,3-triol (propan-1,2,3-triol)	Correct	5	6.1	1.60	1.342	8	22.2	2.13	1.808
	Partially	32	39.0	1.81	1.061	18	50.0	2.00	1.138
	Incorrect	26	31.7	2.35	1.441	8	22.2	2.38	0.916
	No response	19	23.2	—	—	2	5.6	—	—
Interaction (interakcija)	Correct	41	50.0	1.59	1.224	19	52.8	2.05	1.268
	Partially	3	3.7	1.67	1.155	1	2.8	1.00	0.000
	Incorrect	31	37.8	2.19	1.424	15	41.7	2.40	1.183
	No response	7	8.5	—	—	1	2.8	—	—
Energy (energija)	Correct	16	19.5	1.94	1.611	5	13.9	3.40	1.817
	Partially	7	8.5	1.71	0.951	1	2.8	3.00	0.000
	Incorrect	34	41.5	2.26	1.333	15	41.7	2.47	1.060
	No response	25	30.5	—	—	15	41.7	—	—
Solution (otopina)	Correct	12	14.6	1.33	0.651	10	27.8	1.90	1.663
	Partially	21	25.6	1.86	1.526	11	30.6	1.45	0.934
	Incorrect	39	47.6	1.79	1.196	14	38.9	1.93	1.207
	No response	10	12.2	—	—	1	2.8	—	—
Orbital (orbitala)	Correct	1	1.2	1.00	0.000	3	8.3	1.67	1.155
	Partially	20	24.4	1.65	1.226	4	11.1	2.75	0.957
	Incorrect	42	51.2	2.24	1.122	25	69.4	2.52	1.194
	No response	19	23.2	—	—	4	11.1	—	—
Interpretation (interpretacija)	Correct	37	45.1	2.16	1.259	27	75.0	2.48	1.014
	Partially	2	2.4	2.50	2.121	2	5.6	1.50	0.707
	Incorrect	27	32.9	1.74	0.859	3	8.3	2.00	1.000
	No response	16	19.5	—	—	4	11.1	—	—
Valence electrons (valentni elektroni)	Correct	29	35.4	1.76	1.431	24	66.7	2.12	1.191
	Partially	37	45.1	1.62	1.063	6	16.7	2.33	0.516
	Incorrect	4	4.9	2.00	1.155	3	8.3	3.00	1.000
	No response	12	14.6	—	—	3	8.3	—	—
Ionic bond (ionska veza)	Correct	1	1.2	1.00	0.000	0	0.0	—	—
	Partially	62	75.6	1.56	1.223	29	80.6	2.24	1.215
	Incorrect	10	12.2	2.20	1.476	5	13.9	2.20	1.095
	No response	9	11.0	—	—	2	5.6	—	—
Resonance (rezonancija)	Correct	0	0.0	—	—	0	0.0	—	—
	Partially	8	9.8	1.75	0.886	2	5.6	3.00	0.000
	Incorrect	48	58.5	2.42	1.350	20	55.6	2.80	1.322
	No response	26	31.7	—	—	14	38.9	—	—
Charge size (nabojni broj)	Correct	0	0.0	—	—	1	2.8	5.00	0.000
	Partially	17	20.7	1.88	1.054	9	25.0	2.44	1.424
	Incorrect	39	47.6	2.05	1.234	23	63.9	2.61	1.406
	No response	26	31.7	—	—	3	8.3	—	—
Trigonal bipyramid (trigonalna bipiramida)	Correct	0	0.0	—	—	1	2.8	2.00	0.000
	Partially	13	15.9	1.85	1.068	6	16.7	3.17	1.329
	Incorrect	32	39.0	2.50	1.414	7	19.4	4.14	1.215
	No response	37	45.1	—	—	22	61.1	—	—

Table 7 (*continued*)

		Undergraduates		Self-confidence		Graduates		Self-confidence	
		n	%	Mean	St. dev.	*n*	%	Mean	St. dev.
Reduction potential (redukcijski potencijal)	Correct	0	0.0	—	—	0	0.0	—	—
	Partially	11	13.4	2.64	1.027	15	41.7	2.60	1.183
	Incorrect	32	39.0	2.59	1.188	12	33.3	3.08	1.240
	No response	39	47.6	—	—	9	25.0	—	—

The intended best response for Item 3 was statement 1, which was selected by a much larger percentage of undergraduates (41%) than graduates (14%). A breakdown of the choice of distractors is shown in Table 6.

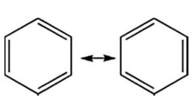
We can see from Table 6 that many more graduate students (18%) selected distractor 2, which could be seen to be consistent with the meaning of *karbonizacija* taken to be "carbonization". Given a probable expanded knowledge base of the graduates, this result is not surprising. Compared with the undergraduates, 9% more graduates also chose distractor 3, probably confusing the term *karbonizacija* with that for "caramelization".

Fourth block of tasks

The students' task was to provide a brief explanation of the meaning of each of the twenty terms and symbols, as well as to provide an estimate on a Likert scale of their confidence that their explanation is correct. The results are shown in Table 7 for word-based language terms, and in Table 8 for symbolic terms.

Among the 13 scientific terms, the three that were satisfactorily explained by most students were *mass number* (37.8% undergraduates, 63.9% graduates), *valence electrons* (35.4%, 66.7%), and *interaction* (50.0%, 52.8%). Even in these cases, the data warn us that future teachers in Croatia cannot presume general understanding of the terms – especially at the undergraduate levels. Very small percentages of the students demonstrated an ability to adequately explain the meaning of most of the terms. These included *resonance* (0%, 0%), *reduction potential* (0%, 0%), *ionic bond* (1.2%, 0%) *charge size* (0%, 2.8%), *trigonal bipyramid* (0%, 2.8%), *orbital* (1.2%, 8.3%) and *corpuscular* (2.4%, 13.9%). Perhaps these terms refer to quite abstract concepts, but very moderate percentages of students explained well the more concrete terms *propan-1,2,3-triol*, *energy*, *solution*, and the representation of benzene resonance.

Table 8 Percentages of undergraduates and graduates who demonstrated the understanding of symbolic terms, and measures of the self-confidence in their answers

		Undergraduates		Self-confidence		Graduates		Self-confidence	
		n	(%)	Mean	St. dev.	*n*	(%)	Mean	St. dev.
$CuSO_4{\cdot}5H_2O(s)$	Correct	72	87.8	1.43	1.208	21	58.3	1.86	1.493
	Partially	2	2.4	1.50	0.707	13	36.1	1.77	1.363
	Incorrect	3	3.7	1.67	1.155	2	5.6	2.50	2.121
	No response	5	6.1	—	—	0	0.0	—	—
$<$	Correct	69	84.1	1.56	1.343	32	88.9	1.81	1.533
	Partially	0	0.0	—	—	0	0.0	—	—
	Incorrect	9	11.0	1.11	0.333	2	5.6	1.00	0.000
	No response	4	4.9	—	—	2	5.6	—	—
	Correct	27	32.9	1.52	1.189	13	36.1	2.15	1.281
	Partially	32	39.0	1.78	1.313	8	22.2	1.88	0.991
	Incorrect	16	19.5	2.25	1.438	9	25.0	2.56	1.424
	No response	7	8.5	—	—	6	16.7	—	—
μ	Correct	53	64.6	1.60	1.182	20	55.6	2.00	1.026
	Partially	6	7.3	2.33	2.066	1	2.8	5.00	0.000
	Incorrect	8	9.8	3.00	1.927	9	25.0	2.33	1.000
	No response	15	18.3	—	—	6	16.7	—	—
$kg\ m^{-3}$	Correct	55	67.1	1.53	1.136	25	69.4	2.00	1.291
	Partially	9	11.0	1.56	1.130	6	16.7	2.67	1.966
	Incorrect	6	7.3	2.00	1.414	3	8.3	2.00	1.732
	No response	12	14.6	—	—	2	5.6	—	—
$A = N(p^+) + N(n^0)$	Correct	51	62.2	1.39	1.115	23	63.9	1.96	1.461
	Partially	8	9.8	2.00	1.852	3	8.3	2.67	1.528
	Incorrect	11	13.4	2.64	1.629	8	22.2	2.50	1.309
	No response	12	14.6	—	—	2	5.6	—	—

Less than half of the undergraduates could explain the meaning of the word *interpretation*, which is used widely in non-science fields, as well as in science. Decidedly more graduates showed knowledge of the meaning of this term. Both undergraduate and graduate students who gave incorrect explanations of the meaning of *interpretation* expressed stronger self-confidence than students who responded correctly.

By and large, more students correctly described the meaning of the symbolic terms than the scientific words. By far the highest number of students demonstrated that they knew the meaning of the *less than* symbol, $<$(84.1%, 88.9%). Perhaps surprisingly, the formula of copper(II) sulfate pentahydrate was explained by 87.8% of undergraduates, but only 58.3% of graduates. While moderate percentages of the order of 55–70% of students could explain the meaning of the symbolic language μ, kg m^{-3}, and $A = N(p^+) + N(n^0)$, these findings also tell us that 30–45% of students probably do not understand these terms well when used by a teacher, or seen in a textbook.

Statistically significant differences between undergraduates and graduates were found for seven terms. Graduates demonstrated a significantly better understanding of the terms *propane-1,2,3-triol* (χ^2 = 6.009, df = 2, p = 0.050), *mass number* (χ^2 = 8.596, df = 2, p = 0.014), *orbital* (χ^2 = 6.563, df = 2, p = 0.038), *interpretation* (χ^2 = 10.194, df = 2, p = 0.006), *valence electrons* (χ^2 = 11.105, df = 2, p = 0.004) and *reduction* (χ^2 = 6.383, df = 2, p = 0.012). Undergraduates were more successful in the explanation of the term $CuSO_4{\cdot}5H_2O(s)$ (χ^2 = 26.380, df = 2, $p < 0.000$)

With respect to the data on students' estimates of self-confidence, for all terms, regardless of whether correct, partially correct, or incorrect, the undergraduates demonstrated at least as much confidence in their understanding than the graduates. This was so even for those terms (most of them) which were correctly described by more graduates than undergraduates. The term for which undergraduate students had least confidence in their answers was *corpuscular*, presumably consistent with the fact that 80% of them did not attempt a description.

For nine of the terms and symbols, the number of undergraduates who chose "highly confident" was statistically significantly greater than the number of graduates who did so. These were: "mass number" (χ^2 = 16.045, df = 4, p = 0.003); "interaction" (χ^2 = 9.818, df = 4, p = 0.044); "valence electrons" (χ^2 = 17.443, df = 4, p = 0.002); "ionic bond" (χ^2 = 15.028, df = 4, p = 0.005); "$CuSO_4{\cdot}5H_2O$" (χ^2 = 11.679, df = 4, p = 0.020); benzene resonance forms (χ^2 = 11.503, df = 4, p = 0.021); "μ" (χ^2 = 18.713, df = 4, p = 0.001); "kg m^{-3}" (χ^2 = 9.650, df = 4, p = 0.047); "$A = N(p^+) + N(n^0)$" (χ^2 = 11.806, df = 4, p = 0.019).

These findings may be consistent with the Dunning–Kruger effect reported by Pazicni and Bauer (2014) that low-performing students overestimate their performance while high-performing students underestimate their performance. These "illusions of competence" exhibited by the unskilled are attributed to the fact of not being able to recognise their own mistakes. It seems that low levels of cognition are accompanied by low levels of metacognition. In this study, differentiation is made between undergraduates and graduates, rather than between low-performing and high-performing students, although an important factor may be the level of content knowledge.

Conclusions

We have found that it cannot be presumed that the students in this study, both undergraduate and graduate, understand the meaning of scientific words, symbolic representations or everyday words that are used in teaching and learning chemistry. There are considerable differences in the extent of understanding, from word to word, and symbol to symbol.

Evidence of inadequate understanding was found regardless of whether the design of the task involved (i) the creation of a scientifically sensible sentence using the key word provided without context, as in Block 1A, (ii) the explanation of the meaning of a word provided in a contextual sentence, as in Block 1B, (iii) the selection of the appropriate usage of a term from multiple-choice options, as in Block 2, or (iv) the explanation of the meaning of a word provided without context, as in Block 4. Although the same terms were not tested by the different kinds of tasks, the findings of this triangulated methodology provide convincing confirmation of the prevalence of poor comprehension levels.

Implications for practice

The authors have conducted this research as chemists and chemical educators curious to find out if in Croatia there are language comprehension problems similar to those that have been found in English speaking countries. We are not linguists. Hence the study is necessarily diagnostic, rather than analytical. We cannot draw on a linguistic knowledge base to make recommendations for action. Rather, we will appeal to common sense, and will borrow from the recommendations of other researchers in this field.

Firstly, we acknowledge, as does Louisa (1989), that teachers cannot avoid using the everyday language that the pupils are familiar with. Part of a teacher's PCK should be the recognition of instances when this might interfere with the desired learning.

Pyburn *et al.* (2013) recommended that instruction in chemistry should include the development of language comprehension ability. Of course, this begs questions about the design of such integrative instruction. Cassels and Johnstone (1980) suggested that the various connotations of words, words that sound similar, and words with similar meanings should be explicitly discussed with students. They further suggested that, to allow students to gradually progress from everyday language, students should be given the opportunity to express the meanings of scientific terms in their own words.

Taskin and Bernholt (2014) suggested the use of reflective tasks that require students to think about and communicate not only their conceptual understanding but also their understanding of the language used. Of course some instructors would respond to this recommendation with concern about re-allocation of time apart from learning the chemistry content. Perhaps we need to balance the loss of the amount of content "covered" against the increase in comprehension through mastery of the associated language.

Interactive class discussions that use argumentation and reflection to enhance the understanding of the language of chemistry instruction could well focus on specific issues, such as the following:

• Differentiation between similar-sounding words, such as *težište* and *težnja*, or *frakcija* and *fraktura*.

• Differentiation between words with subtly different scientific meanings, such as *proportion* and *ratio*.

• Clarification of the different everyday and scientific meanings of certain words, such as *reduction*, *dispersion*, *mass*, *spontaneous*, and *saturated*.

• Distinction between the meanings of symbols that might be confused with each other, such as the large variety of arrows that are used in chemistry.

• Clarification of the variety of functions that a number (such as 2) can have in a chemical equation.

• Recognition that certain words apply to different ''triplet'' levels, such as *compound* and *molecule*.

• Drawing attention to ''levels of confusion'': the attribution of characteristics applicable to one ''triplet'' level to another level, such as attribution of copper's malleability to malleability of copper atoms, or the nonsensical statement sometimes seen in textbook exercises: ''Which of the following molecules has the highest surface tension?''

As more research studies demonstrate the prevalence of poor language comprehension, with which is necessarily associated less-than-desirable conceptual understanding, perhaps this issue is important enough to warrant inclusion for its own sake in assessments – at least in formative testing. Indeed it seems appropriate to use examples of questions in the diagnostic instrument used in this research as test items. The results of the assessments could be used as focal points for the reflective discussions referred to immediately above.

So far in this discussion there has been a tacit assumption of the simultaneous development of conceptual and language comprehension. Song and Carheden (2014) pointed out that students' everyday meanings of terms that have different meanings in the science context have long been considered as a barrier or deficit in chemistry education. Given that students will bring with them their everyday meanings, these writers discuss an approach in which teachers and students use everyday language to develop understanding of science content prior to learning the scientific vocabularies. For example, in the context of teaching the main ideas related to photosynthesis, Brown and Ryoo (2008) found that students retained the vocabulary and concepts better when the scientific meanings were first introduced with students' everyday language before teaching the scientific terms. These researchers have developed the ''disaggregate instruction'' model in which the conceptual part of a science topic and a language part are taught separately (Brown *et al.*, 2010).

As noted by Song and Carheden (2014), research on students' attainment of understanding the language of science is at an early stage. Further research will be key to understanding how language can be taught and learned with greater efficacy.

A concomitant challenge is knowledge transfer from research findings to the PCK of teachers through some form of professional development. How do chemistry teachers develop the PCK that comprises the knowledge, methodology and skills that research suggests is warranted? By and large, if there are components of chemistry education conferences devoted to language comprehension issues, they are rather general, and point to the possible existence of problems, rather than to describe the problems specifically and analytically in a way that suggests courses of action. In Croatia, at least, language comprehension issues have played negligible parts of professional development courses. There are strong reasons for this situation to change.

Future research

We have explored tertiary students' understanding of only a relatively tiny sample of scientific words and symbols, as well as everyday words that commonly constitute the communication used in teaching and learning chemistry in Croatia. Although we have seen some evidence of confusion between similar sounding words, and between the everyday and scientific meanings of words, we cannot claim to have explored the characteristics of words that are likely to present problems of comprehension to tertiary level students. Nor has the extent of (assumed) improvement as students advance through their tertiary studies been monitored – perhaps during a longitudinal study. Similarly we have not investigated the characteristics of those chemical symbols that are least poorly understood.

We have not explored the extent to which language issues in the Croatian system are common with those in countries with other languages of instruction, or difficulties that are peculiar to the Croatian system, or the reasons that these might exist. Since chemical symbols are universal, at first reaction we might hypothesise that comprehension levels of symbols are similar for all countries. But to do so would be to ignore the contexts in which topics are presented in different countries, the labels given to the symbols, the characteristic scientific language used to describe the symbols, and the existence of everyday words that might interact with scientific comprehension.

We might furthermore wonder about the precision of the understanding of words and symbols of instructors in the tertiary system. Hopefully more significant unknowns might be the level of pedagogical content knowledge of the teachers: the extent to which they are aware of the possibility of students' language comprehension issues, as well as the degree of cognition of useful strategies to deal with such problems, either preventatively or curatively. Action research studies, no matter how small, to monitor the effectiveness of strategies, such as those suggested above, followed by the re-design of strategies, and monitoring effectiveness once again, might be useful.

Appendix

(a) Second block's multiple choice questions in Croatian

Zaokružite tvrdnju koju smatrate ispravnom.

I. Benzin je **derivat** nafte. To znači da je benzin

(1) lako hlapljiva tekućina.

(2) samo jedan od mnogih dijelova nafte.

(3) dobiven iz nafte.
(4) isto što i nafta.

II. U kojoj je rečenici riječ **modifikacija** smisleno upotrijebljena?
(1) Modifikacija kukuruza je dugo trajala, ali baš se ništa promijenilo nije.
(2) Reći ću ti broj mobitela kad se zgotovi modifikacija posljednjih znamenki.
(3) Zahtjevna modifikacija dijamanta izvedena je brusom od titana!
(4) Osnovni cilj odgajatelja u vrtiću ''Centar grada'' jest modifikacija dječjeg ponašanja.

III. U kojoj je rečenici riječ **karbonizacija** smisleno upotrijebljena?
(1) Karbonizacija je nužan proces u nastanku gazirane vode.
(2) Karbonizacija drveta bijaše tolikih razmjera da je plamen zahvatio zavjese u kući.
(3) Karbonizacija šećera temelj je proizvodnje slasnih šećernih ukrasa za svadbene torte.
(4) Karbonizacijom bijelog brašna pod visokim tlakom nastaje ljepilo.

IV. U kojoj je rečenici riječ **neutralizirati** ispravno upotrijebljena?
(1) Slana će otopina neutralizirati slatku.
(2) Moja petica iz znanja neutralizirat će trojku iz zalaganja.
(3) Nuspojave smo mogli neutralizirati novim lijekom.
(4) Moja petica iz zalaganja neutralizirat će trojku iz znanja.

V. **Ograničenje** brzine je 40 km h^{-1}. To znači da automobil treba voziti
(1) ne brže od 40 km h^{-1}.
(2) točno 40 km h^{-1}.
(3) brže ili sporije od 40 km h^{-1}, ali nikako 40 km h^{-1}
(4) približno 40 km h^{-1}.

VI. U kojoj je rečenici riječ **efekt** ispravno upotrijebljena?
(1) Nije bilo planirano – udario ga je u efektu!
(2) Efekt grijanja vode je da vrije.
(3) Lopta je imala veliki efekt s obzirom na putanju kojom je stigla do mreže.
(4) Nakon popravka automobil se nije mogao pokrenuti – i dalje je imao efekt.

VII. U kojoj je rečenici riječ **simultano** smisleno upotrijebljena?
(1) Simultano ponašanje odlika je paličnjaka – toliko su nalik grančicama da su nezamjetni.
(2) Baš zato što je drugačiji, njen je naglasak zvučao simultano.
(3) Detaljno proučivši lice u zrcalu, zaključila je da se lijeva i desna polovica ipak ne odnose simultano.
(4) Dvije eksplozije su aktivirane simultano pa zvučahu kao jedna.

VIII. U kojoj je rečenici riječ **konzistentan** ispravno upotrijebljena?
(1) Maslac je bio konzistentan pri sobnoj temperaturi.
(2) Njen je odvjetnik prečesto konzistentan, a ne pruža kvalitetne savjete?
(3) Ručak je bio konzistentan u kratkom vremenu jer bijaše neobično slastan.
(4) Konzistentan proizvod bez konzervansa nije trajan.

IX. Izračunat je **postotak** ulja u maslinama. To znači da je utvrđeno
(1) koliko se stotih dijelova nekog broja odnosi na ulje u maslinama.
(2) koliki je prosječni urod maslina.
(3) koliki je udio slobodnih viših masnih kiselina.
(4) koliki je volumni udio ulja u maslinama.

X. Cvjetača se **dezintegrira** ako se dovoljno dugo kuha. To znači da
(1) promijeni boju.
(2) se raspadne na manje dijelove.
(3) reagira sa soli otopljenom u vodi.
(4) se očisti od mikroorganizama.

XI. U kojoj je rečenici riječ **formiranje** smisleno upotrijebljena?
(1) Formiranje problema nužan je korak u pisanju znanstvenog rada.
(2) Kreativnost i formiranje ne idu zajedno.
(3) Formiranje ''živog zida'' pokazalo se neuspješnim.
(4) Uspješno formiranje na sadržaj temelj je uspjeha svakog studenta.

XII. Otkrivene su čestice imale **naboj**. To znači da su čestice
(1) bile neutralne.
(2) uzrokovale kiselost.
(3) sadržavale nejednak broj pozitivnih i negativnih dijelova.
(4) bile dobri vodiči električne struje.

XIII. Zagađenje je dokazano **elementarnom** analizom. To znači da je analiza bila
(1) najosnovnija.
(2) vrlo složena.
(3) kemijska.
(4) fizikalna.

XIV. U kojoj je rečenici pravilno upotrijebljena riječ **proporcija**?
(1) Bijaše mu malo pet proporcija ukusne orahnjače; htio je još!
(2) Proporcije nagradne igre uvijek su istaknute na stranici organizatora.
(3) Svaki ekonomist zna izraditi proporciju troškova za sljedeću godinu.
(4) Proporcija njihovog vlasništva bila je očita – svaki je posjedovao četvrtinu dionica tvrtke.

XV. Izradio je **planarni** prikaz njene kuće. To znači da je izradio
(1) model.
(2) nacrt.
(3) maketu.
(4) plan gradnje.

XVI. U kojoj je rečenici riječ **frakcija** ispravno upotrijebljena?
(1) Frakciju lubanje zadobio je padom s motocikla.
(2) Frakcija je komplet koji su nosili muškarci u 19. stoljeću – frak i šešir, rukavice i štap.
(3) Ekstremna frakcija stranke 'DPDPMO' je izvela puč i preuzela vlast.
(4) Frakcija je crkveni red kojem pripadaju Franjevci.

VII. Političar je svoje stavove **sublimirao** na pola stranice. To znači da ih je

(1) sažeto i jezgrovito prikazao.

(2) razbacao po papiru.

(3) otvoreno predočio.

(4) tek površno naveo.

XVIII. U kojoj je rečenici riječ **generalizacija** pravilno upotrijebljena?

(1) Generalizacija podataka je nužna da bismo izveli valjani zaključak.

(2) Prošlogodišnja generalizacija studenata najzaslužnija je za dobar prosjek fakulteta.

(3) Generalizacija novih virusa ugrožava opstanak Sibirskog tigra.

(4) Generalizacija će omogućiti precizan uvid u svaki od slučajeva.

XIX. U kojoj je rečenici riječ **permanentni** ispravno upotrijebljena?

(1) Svaki flomaster s rupicama na kućištu, naziva se permanentni flomaster.

(2) Permanentni je pritisak urodio plodom.

(3) Nastup TBF-a bio je permanentni događaj na koncertu Rolling Stonesa u Zagrebu.

(4) Permanentni se lijepak lako odvaja od podloge.

XX. U kojoj je rečenici riječ **donirati** ispravno upotrijebljena?

(1) Lijek je potrebno donirati prema tjelesnoj masi.

(2) Prekršaj treba donirati i pohraniti u plavom registratoru.

(3) Nezbrinutoj djeci donirat će plišane medvjediće.

(4) Samo je jedan natjecatelj bio u stanju donirati nad ostalima.

(b) Second block's multiple choice questions translated into English

Circle the statement that you consider to be correct.

I. Gasoline is a **derivative** of naphtha. This means that gasoline

(1) is a highly volatile liquid.

(2) is only one of many parts of petroleum.

(3) is obtained from petroleum.

(4) is the same as petroleum.

II. In which sentence is the word **modification** sensibly used?

(1) Modification of corn lasts a long time, but really nothing changed.

(2) I'll tell you the cell phone number when modification of the last digits has been done.

(3) The required modification of the diamond was performed with a titanium grinding wheel!

(4) The basic objective of the educators in the ''City Centre'' kindergarten is modification of child behaviour.

III. In which sentence is the word **carbonization** meaningfully used?

(1) Carbonization is a necessary process in the development of carbonated water.

(2) Carbonization of wood was at such scale that flame engulfed the curtains in the house.

(3) Carbonization of sugar is the basis of production of delicious sugar decorations for wedding cakes.

(4) Carbonization of white flour at high pressure results in glue.

IV. In which sentence the word **neutralize** is used properly?

(1) A salt solution will neutralize a sweet one.

(2) My ''A'' for knowledge will neutralize the ''C'' for the activity.

(3) Side effects could be neutralized with a new drug.

(4) My ''A'' for the activity will neutralize the ''C'' for knowledge.

V. The speed **limit** is 40 km h^{-1}. This means that cars need to travel

(1) at not more than 40 km h^{-1}.

(2) at exactly 40 km h^{-1}.

(3) faster or slower than 40 km h^{-1}, but not at exactly 40 km h^{-1}

(4) at approximately 40 km h^{-1}.

VI. In which sentence is the word **effect** used properly?

(1) It wasn't planned – he hit him in effect!

(2) The effect of heating water is that it boils.

(3) The ball had a great effect with regard to the pathway by which it reached the net.

(4) After the service, the car could not be started – the effect was still there.

VII. In which sentence is the word **simultaneously** meaningfully used?

(1) Simultaneously acting is a characteristic of stick insects – they are so similar to twigs that they are inconspicuous.

(2) Just because she's different, her accent sounded simultaneously.

(3) Thoroughly studying the face in the mirror, she concluded that the left and right halves are not related simultaneously.

(4) The two explosions were initiated simultaneously so they sounded like one.

VIII. In which sentence the word **consistent** is used properly?

(1) At room temperature, the butter was consistent.

(2) Her lawyer was consistent too often, and he didn't provide useful advice?

(3) The lunch was consistent in a short time because it was unusually delicious.

(4) The consistent product without preservative does not last long.

XIX. The **percentage** of oil in olives is calculated. This means that what is calculated is

(1) how many hundredth parts of some number there are in relation to the oil in the olives.

(2) how big is the average yield of olives.

(3) how big is the proportion of free higher fatty acids.

(4) how big is the volume fraction of oil in the olives.

X. When cauliflower is boiled for too long it **disintegrates**. This means that it

(1) changes colour.

(2) breaks up into smaller pieces.

(3) reacts with salt dissolved in water.

(4) is cleaned of microorganisms.

XI. Which sentence uses the word **formation** correctly?

(1) Formation of the problem is a necessary step in writing a scientific paper.

(2) Creativity and formation do not go together.

(3) Formation of human shields was shown to be unsuccessful.

(4) Successful formation of the content is the basis of success for each student.

XII. The detected particles had a **charge**. This means that the particles

(1) were neutral.

(2) caused acidity.

(3) contained an unequal number of positive and negative parts.

(4) are good conductors of electricity.

XIII. The pollution was proven by **elemental** analysis. This means that the analysis was

(1) the most basic.

(2) very complex.

(3) chemical.

(4) physical.

XIV. In which sentence is the word **proportion** correctly used?

(1) Five proportions of delicious walnut cake weren't enough for him; he wanted more!

(2) Proportions of lottery games are always highlighted on the website of the organizer.

(3) Every economist knows how to prepare the proportion of costs for next year.

(4) The proportion of their ownership was obvious – each of them owned a quarter of the company's stock.

XV. He made a **planar** view of her house. This means that he made

(1) a model.

(2) a draft.

(3) a mock up.

(4) a building plan.

XVI. In which sentence is the word **fraction** used correctly?

(1) The fraction of the skull sustained by fall from motorcycle.

(2) Fraction is the set that are worn by men in the 19th century – a dress coat and hat, gloves and stick.

(3) The extreme fraction of the ''DPDPMO'' party have performed a coup and taken power.

(4) Fraction is the religious order to which Franciscans belongs.

XVII. The politician **sublimated** his views on half a page. This means that he

(1) concisely and succinctly presented them.

(2) dispersed them across the paper.

(3) openly presented them.

(4) only superficially mentioned them.

XVIII. In which sentence is the word **generalization** used correctly?

(1) The generalization of data is necessary in order to reach a valid conclusion.

(2) Last year's generalization of students is the most deserving for a good faculty average result.

(3) The generalization of new viruses threatens the survival of the Siberian tiger.

(4) Generalization will enable accurate insight into each of the cases.

XIX. Which sentence uses the word **permanent** correctly?

(1) Each marker with holes in its base is called a permanent marker.

(2) Permanent pressure bore fruit.

(3) Performance of TBF was a permanent event at the Rolling Stones concert in Zagreb.

(4) Permanent glue is easily separated from the substrate.

XX. In which sentence is the word **donate** used correctly?

(1) This drug should donate according to body mass.

(2) The case should be donated and stored in a blue binder.

(3) Stuffed bears will be donated to orphans.

(4) Only one rider was able to donate over others.

Acknowledgements

We appreciate all of the students who have been involved in this research. We also wish to thank mr sc. Marina Luetić who helped us as a chemistry expert and critical friend.

References

Brown B. A., (2011), Isn't that just good teaching? Disaggregate instruction and the language identity dilemma, *J. Sci. Teacher Educ.*, **22**, 679–704.

Brown B. A. and Ryoo K., (2008), Teaching Science as a Language: A ''Content-First'' Approach to Science Teaching, *J. Res. Sci. Teach.*, **45**(5), 529–553.

Brown B. and Spang E., (2008), Double talk: synthesizing everyday and science language in the classroom, *Sci. Educ.*, **92**, 708–732.

Brown B. A., Ryoo K. and Rodriguez J., (2010), Pathway towards fluency: using 'disaggregate instruction' to promote science literacy, *Int. J. Sci. Educ.*, **32**(11), 1465–1493.

Bucat R., (2004), Pedagogical content knowledge as a way forward: applied research in chemistry education, *Chem. Educ. Res. Pract.*, **5**(3), 215–228.

Bucat B. and Mocerino M., (2009), Learning at the sub-micro level: structural representations, in Gilbert J. K. and Treagust D. (ed.) *Multiple Representations in Chemical Education*, Springer, ISBN 978-1-4020-8871-1, pp. 11–29.

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

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

Clerk D. and Rutherford M.,(2000), Language as a cofounding variable in the diagnosis of misconceptions, *Int. J. Sci. Educ.*, **22**(7), 703–717.

Farrell M. and Ventura F., (1998), Words and understanding in physics, *Lang. Educ.*, **12**(4), 243–254.

Gabel D., (1999), Improving teaching and learning through chemistry education research: a look to the future, *J. Chem. Educ.*, **76**, 548–554.

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

Jasien P. G., (2010), You said ''neutral'', but what do you mean? *J. Chem. Educ*., **87**(1), 33–34.

Jasien P. G., (2011), What do you mean that ''strong'' doesn't mean ''powerful''? *J. Chem. Educ*., **88**, 1247–1249.

Johnstone A. H., (1982), Macro- and micro-chemistry, *Sch. Sci. Rev*., **64**, 377–379.

Johnstone A. H., (1991), Why is science difficult to learn? Things are seldom like they seem, *J. Comput. Assist. Lear.*, **7**, 75–83.

Johnstone A. H. and Selepeng D., (2001), A language problem revisited, *Chem. Educ.: Res. Pract. Eur.*, **2**(1), 19–29.

Laszlo P., (2002), Describing reactivity with structural formulas, or when push comes to shove, *Chem. Educ. Res. Pract*., **3**(2), 113–118.

Louisa M., Veiga F. C. S., Costa Pereira D. J. V. and Maskill R., (1989), Teachers' language and pupils' ideas in science lessons: can teachers avoid reinforcing wrong ideas? *Int. J. Sci. Educ*., **11**(4), 465–479.

Lynch P. P., Benjamin P., Chapman T., Holmes R., McCammon R., Smith A. and Symmons R., (1979), Scientific language and the high school pupil, *J. Res. Sci. Teach.*, **16**(4), 351–357.

Magnusson S., Krajcik J. and Borko H., (1999), Nature, sources, and development of pedagogical content knowledge for science teaching, in Gess-Newsome J. and Lederman N. G. (ed.) *Examining pedagogical content knowledge: the construct and its implications for science education*, Boston, MA: Kluwer, pp. 95–132.

Marais P. and Jordaan F. (2000), Are we taking symbolic language for granted? *J. Chem. Educ*., **77**(10), 1355–1357.

Marshall S., Gilmour M. and Lewis D., (1991), Words that matter in science and technology, *Res. Sci. Tech. Educ.*, **9**(1), 5–16.

Meyerson M., Ford M., Jones W. and Ward M., (1991), Science vocabulary knowledge of third and fifth grade students, *Sci. Educ.*, **75**(4), 419–428.

Pickersgill S. and Lock R., (1991), Student understanding of selected non-technical word sin science, *Res. Sci. Tech. Educ.*, **9**(1), 71–79.

Pazicni S. and Bauer C. F., (2014), Characterizing illusions of competence in introductory chemistry students, *Chem. Educ. Res. Pract.*, 2014, **15**(1), 24–34.

Pyburn D. T., Pazicni S., Victor A., Benassi V. A., and Elizabeth E. Tappin E. E., (2013), Assessing the relation between language comprehension and performance in general chemistry, *Chem. Educ. Res. Pract.*, **14**(4), 524–541.

Shulman L. S., (1986), Those who understand: Knowledge growth in teaching, *Educ. Res.*, **15**(2), 4–14.

Shulman L. S., (1987), Knowledge and teaching: Foundations of the new reform, *Harvard Educ. Rev.*, **57**, 1–22.

Snow C. E., (2010), Academic language and the challenge of reading for learning about science, *Science*, **328**(23), 450–452.

Song Y. and Carheden S., (2014), Dual meaning vocabulary (DMV) words in learning chemistry, *Chem. Educ. Res. Pract.*, **15**(2), 128–141.

Stieff M., Ryu M. and Yip J. C., (2013), Speaking across levels – generating and addressing levels confusion in discourse, *Chem. Educ. Res. Pract.*, **14**, 376–389.

Taber K. S., (2002), *Misconceptions in chemistry – prevention, diagnosis and cure*, London: Royal Society of Chemistry.

Taber K. S., (2009), Learning at the symbolic level, in Gilbert J. K. and Treagust D. (ed.) *Multiple Representations in Chemical Education*, Springer, ISBN 978-1-4020-8871-1, pp. 75–105.

Taber, K. S., (2013) Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education, *Chem. Educ. Res. Pract.*, **15**, 156–168.

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

Talanquer V. (2011), Macro, Submicro, and Symbolic: the many faces of the chemistry ''triplet'', *Int. J. Sci. Educ*, **33**(2), 179–195.

Taskin V. and Bernholt S., (2014), Students' Understanding of Chemical Formulae: A review of empirical research, *Int. J. Sci. Educ*., **36**(1), 157–185.

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

Yong B. C. S., (2003), Language problems in the learning of biology through the medium of English, *J. Appl. Res. Educ.*, **7**(1), 97–104.