Understanding of words and symbols by chemistry university students in Croatia

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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.

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...
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 interpreta-
tion 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, 
Steff 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 equa-
tions (such as \( \Delta H > 0 \), \( \rightarrow \), \( \text{[NO}_2\text{]} \), and \( 2\text{NO}_2 \)). 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 examina-
tion 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 com-
pletely. 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 cate-
gories 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 interpreta-
tion of formulæ.

The literature reviewed provides evidence that both the 
technical and non-technical vocabulary of chemistry pose prob-
lems 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 com-
prehend 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 gra-
duation. 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 institu-
tional 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
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) *težna*, 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). (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 (*polušjer* and radius) are commonly used for radius, and two words (*promjer* and *dijameter*) are used for diameter. Confusion among these terms is perhaps the reason that six students wrote “polušjer is half the radius.”
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” ($\chi^2 = 12.837, df = 2, p = 0.002$).

### 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 ($\chi^2 = 7.607, df = 1, p = 0.006$), better understood by undergraduates, and simultaneously ($\chi^2 = 6.860, df = 1, p = 0.009$), better understood by graduates.

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

### Table 2

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

<table>
<thead>
<tr>
<th>Terms</th>
<th>Undergraduates</th>
<th>Graduates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractive forces between molecules are called van der Waals forces.</td>
<td>Correct 34, 41.5%</td>
<td>Graduates 8, 22.2%</td>
</tr>
<tr>
<td>The formula of starch is not simple.</td>
<td>Correct 14, 17.1%</td>
<td>Graduates 4, 11.1%</td>
</tr>
<tr>
<td>Electronegativity is a relative concept.</td>
<td>Correct 15, 18.3%</td>
<td>Graduates 8, 22.2%</td>
</tr>
<tr>
<td>A large and beautifully shaped crystal is rarely found in nature.</td>
<td>Correct 29, 35.4%</td>
<td>Graduates 14, 38.9%</td>
</tr>
<tr>
<td>Although an atom does not have a definite boundary, we often use a measure known as atomic radius.</td>
<td>Correct 52, 63.4%</td>
<td>Graduates 24, 66.7%</td>
</tr>
<tr>
<td>Each orbital can accommodate two electrons of opposite spin.</td>
<td>Correct 2, 2.4%</td>
<td>Graduates 0, 0.0%</td>
</tr>
</tbody>
</table>

### 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

<table>
<thead>
<tr>
<th>Keywords</th>
<th>Undergraduates</th>
<th>Graduates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Derivative (derivat)</td>
<td>71, 85.5%</td>
<td>30, 83.3%</td>
</tr>
<tr>
<td>Modification (modifikacija)</td>
<td>24, 29.3%</td>
<td>12, 34.3%</td>
</tr>
<tr>
<td>Carbonation (karbonizacija)</td>
<td>32, 40.5%</td>
<td>5, 14.3%</td>
</tr>
<tr>
<td>Neutralize (neutralizirati)</td>
<td>32, 39.5%</td>
<td>15, 41.7%</td>
</tr>
<tr>
<td>Limit (ogranicˇenje)</td>
<td>71, 85.5%</td>
<td>33, 91.7%</td>
</tr>
<tr>
<td>Effect (efekt)</td>
<td>41, 50.6%</td>
<td>19, 52.8%</td>
</tr>
<tr>
<td>Simultaneously (simultano)</td>
<td>54, 69.2%</td>
<td>33, 91.7%</td>
</tr>
<tr>
<td>Consistent (konzistentan)</td>
<td>55, 70.5%</td>
<td>30, 83.3%</td>
</tr>
<tr>
<td>Percentage (postotak)</td>
<td>31, 37.4%</td>
<td>15, 41.7%</td>
</tr>
<tr>
<td>Disintegrate (dezintegrirati)</td>
<td>70, 87.3%</td>
<td>34, 94.4%</td>
</tr>
<tr>
<td>Formation (formiranje)</td>
<td>62, 75.6%</td>
<td>27, 75.0%</td>
</tr>
<tr>
<td>Charge (naboj)</td>
<td>69, 83.1%</td>
<td>29, 80.6%</td>
</tr>
<tr>
<td>Elementary (elementarno)</td>
<td>73, 88.0%</td>
<td>30, 83.3%</td>
</tr>
<tr>
<td>Proportion (proporcija)</td>
<td>64, 78.1%</td>
<td>26, 72.2%</td>
</tr>
<tr>
<td>Planar (planarni)</td>
<td>44, 54.3%</td>
<td>23, 63.9%</td>
</tr>
<tr>
<td>Faction (frakcija)</td>
<td>26, 31.3%</td>
<td>16, 47.1%</td>
</tr>
<tr>
<td>Sublimate (sublimirati)</td>
<td>54, 65.9%</td>
<td>29, 80.6%</td>
</tr>
<tr>
<td>Generalization (generalizacija)</td>
<td>36, 70.9%</td>
<td>30, 83.3%</td>
</tr>
<tr>
<td>Permanent (permanentni)</td>
<td>41, 52.6%</td>
<td>16, 47.1%</td>
</tr>
<tr>
<td>Donate (donirati)</td>
<td>81, 98.8%</td>
<td>36, 100.0%</td>
</tr>
</tbody>
</table>

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 simultaneously (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...
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 fraction (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 fraction, 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 4 Percentages of undergraduate and graduate students who responded to each of the choices in item 7 concerning the word simultaneously.

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

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

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

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

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

* 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.

<table>
<thead>
<tr>
<th></th>
<th>Undergraduates</th>
<th></th>
<th>Graduates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>Mean</td>
<td>St. dev.</td>
</tr>
<tr>
<td>Corpuscular (karpuskularno)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>2</td>
<td>2.4</td>
<td>3.50</td>
<td>2.121</td>
</tr>
<tr>
<td>Partially</td>
<td>0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorrect</td>
<td>14</td>
<td>17.1</td>
<td>3.57</td>
<td>1.453</td>
</tr>
<tr>
<td>No response</td>
<td>66</td>
<td>80.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass number (nuleonski broj)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>31</td>
<td>37.8</td>
<td>1.61</td>
<td>1.145</td>
</tr>
<tr>
<td>Partially</td>
<td>16</td>
<td>19.5</td>
<td>1.19</td>
<td>0.403</td>
</tr>
<tr>
<td>Incorrect</td>
<td>27</td>
<td>32.9</td>
<td>2.00</td>
<td>1.544</td>
</tr>
<tr>
<td>No response</td>
<td>8</td>
<td>9.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propane-1,2,3-triol (propan-1,2,3-triol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>5</td>
<td>6.1</td>
<td>1.60</td>
<td>1.342</td>
</tr>
<tr>
<td>Partially</td>
<td>32</td>
<td>39.0</td>
<td>1.81</td>
<td>1.061</td>
</tr>
<tr>
<td>Incorrect</td>
<td>26</td>
<td>31.7</td>
<td>2.35</td>
<td>1.441</td>
</tr>
<tr>
<td>No response</td>
<td>19</td>
<td>23.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction (interakcija)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>41</td>
<td>50.0</td>
<td>1.59</td>
<td>1.224</td>
</tr>
<tr>
<td>Partially</td>
<td>3</td>
<td>3.7</td>
<td>1.67</td>
<td>1.155</td>
</tr>
<tr>
<td>Incorrect</td>
<td>31</td>
<td>37.8</td>
<td>2.19</td>
<td>1.424</td>
</tr>
<tr>
<td>No response</td>
<td>7</td>
<td>8.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (energija)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>16</td>
<td>19.5</td>
<td>1.94</td>
<td>1.611</td>
</tr>
<tr>
<td>Partially</td>
<td>7</td>
<td>8.5</td>
<td>1.71</td>
<td>0.951</td>
</tr>
<tr>
<td>Incorrect</td>
<td>34</td>
<td>41.5</td>
<td>2.26</td>
<td>1.333</td>
</tr>
<tr>
<td>No response</td>
<td>25</td>
<td>30.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solution (otopina)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>12</td>
<td>14.6</td>
<td>1.33</td>
<td>0.651</td>
</tr>
<tr>
<td>Partially</td>
<td>21</td>
<td>25.6</td>
<td>1.86</td>
<td>1.526</td>
</tr>
<tr>
<td>Incorrect</td>
<td>39</td>
<td>47.6</td>
<td>1.79</td>
<td>1.196</td>
</tr>
<tr>
<td>No response</td>
<td>10</td>
<td>12.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orbital (oritala)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>1</td>
<td>1.2</td>
<td>1.00</td>
<td>0.000</td>
</tr>
<tr>
<td>Partially</td>
<td>20</td>
<td>24.4</td>
<td>1.65</td>
<td>1.226</td>
</tr>
<tr>
<td>Incorrect</td>
<td>42</td>
<td>51.2</td>
<td>2.24</td>
<td>1.122</td>
</tr>
<tr>
<td>No response</td>
<td>19</td>
<td>23.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpretation (interpretacija)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>37</td>
<td>45.1</td>
<td>2.16</td>
<td>1.259</td>
</tr>
<tr>
<td>Partially</td>
<td>2</td>
<td>2.4</td>
<td>2.50</td>
<td>2.121</td>
</tr>
<tr>
<td>Incorrect</td>
<td>27</td>
<td>32.9</td>
<td>1.74</td>
<td>0.859</td>
</tr>
<tr>
<td>No response</td>
<td>16</td>
<td>19.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valence electrons (valentni elektroni)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>29</td>
<td>35.4</td>
<td>1.76</td>
<td>1.431</td>
</tr>
<tr>
<td>Partially</td>
<td>37</td>
<td>45.1</td>
<td>1.62</td>
<td>1.063</td>
</tr>
<tr>
<td>Incorrect</td>
<td>4</td>
<td>4.9</td>
<td>2.00</td>
<td>1.155</td>
</tr>
<tr>
<td>No response</td>
<td>12</td>
<td>14.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionic bond (ionska veza)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>1</td>
<td>1.2</td>
<td>1.00</td>
<td>0.000</td>
</tr>
<tr>
<td>Partially</td>
<td>62</td>
<td>75.6</td>
<td>1.56</td>
<td>1.223</td>
</tr>
<tr>
<td>Incorrect</td>
<td>10</td>
<td>12.2</td>
<td>2.20</td>
<td>1.476</td>
</tr>
<tr>
<td>No response</td>
<td>9</td>
<td>11.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resonance (rezonancija)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially</td>
<td>8</td>
<td>9.8</td>
<td>1.75</td>
<td>0.886</td>
</tr>
<tr>
<td>Incorrect</td>
<td>48</td>
<td>58.5</td>
<td>2.42</td>
<td>1.350</td>
</tr>
<tr>
<td>No response</td>
<td>26</td>
<td>31.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charge size (naboji broj)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially</td>
<td>17</td>
<td>20.7</td>
<td>1.88</td>
<td>1.054</td>
</tr>
<tr>
<td>Incorrect</td>
<td>39</td>
<td>47.6</td>
<td>2.05</td>
<td>1.234</td>
</tr>
<tr>
<td>No response</td>
<td>26</td>
<td>31.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trigonal bipyramid (trigonalna bipiramida)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially</td>
<td>13</td>
<td>15.9</td>
<td>1.85</td>
<td>1.068</td>
</tr>
<tr>
<td>Incorrect</td>
<td>32</td>
<td>39.0</td>
<td>2.50</td>
<td>1.414</td>
</tr>
<tr>
<td>No response</td>
<td>37</td>
<td>45.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 7 (continued)

<table>
<thead>
<tr>
<th>Undergraduates</th>
<th>Self-confidence</th>
<th>Graduates</th>
<th>Self-confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>Mean</td>
<td>St. dev.</td>
</tr>
<tr>
<td>Reduction potential (reducijski potencijal)</td>
<td>Correct</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Partially</td>
<td>11</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>Incorrect</td>
<td>32</td>
<td>39.0</td>
</tr>
<tr>
<td></td>
<td>No response</td>
<td>39</td>
<td>47.6</td>
</tr>
</tbody>
</table>

### Table 8

<table>
<thead>
<tr>
<th>Undergraduates</th>
<th>Self-confidence</th>
<th>Graduates</th>
<th>Self-confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>Mean</td>
<td>St. dev.</td>
</tr>
<tr>
<td>CuSO₄·3H₂O(s)</td>
<td>Correct</td>
<td>72</td>
<td>87.8</td>
</tr>
<tr>
<td></td>
<td>Partially</td>
<td>2</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Incorrect</td>
<td>3</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>No response</td>
<td>5</td>
<td>6.1</td>
</tr>
<tr>
<td>&lt;</td>
<td>Correct</td>
<td>69</td>
<td>84.1</td>
</tr>
<tr>
<td></td>
<td>Partially</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Incorrect</td>
<td>9</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>No response</td>
<td>4</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>Correct</td>
<td>27</td>
<td>32.9</td>
</tr>
<tr>
<td></td>
<td>Partially</td>
<td>32</td>
<td>39.0</td>
</tr>
<tr>
<td></td>
<td>Incorrect</td>
<td>16</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>No response</td>
<td>7</td>
<td>8.5</td>
</tr>
<tr>
<td>μ</td>
<td>Correct</td>
<td>53</td>
<td>64.6</td>
</tr>
<tr>
<td></td>
<td>Partially</td>
<td>6</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>Incorrect</td>
<td>8</td>
<td>9.8</td>
</tr>
<tr>
<td></td>
<td>No response</td>
<td>15</td>
<td>18.3</td>
</tr>
<tr>
<td>kg m⁻³</td>
<td>Correct</td>
<td>55</td>
<td>67.1</td>
</tr>
<tr>
<td></td>
<td>Partially</td>
<td>9</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>Incorrect</td>
<td>6</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>No response</td>
<td>12</td>
<td>14.6</td>
</tr>
<tr>
<td>A = N(p⁰) + N(n⁰)</td>
<td>Correct</td>
<td>51</td>
<td>62.2</td>
</tr>
<tr>
<td></td>
<td>Partially</td>
<td>8</td>
<td>9.8</td>
</tr>
<tr>
<td></td>
<td>Incorrect</td>
<td>11</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>No response</td>
<td>12</td>
<td>14.6</td>
</tr>
</tbody>
</table>
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. Decisively 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 \( \mu \), kg m\(^{-3}\), and \( A = N(p^+) + N(n^-) \), 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 (\( \chi^2 = 6.009, df = 2, p = 0.050 \)), mass number (\( \chi^2 = 8.596, df = 2, p = 0.014 \)), orbital (\( \chi^2 = 6.563, df = 2, p = 0.038 \)), interpretation (\( \chi^2 = 10.194, df = 2, p = 0.006 \)), valence electrons (\( \chi^2 = 11.105, df = 2, p = 0.004 \)) and reduction (\( \chi^2 = 6.383, df = 2, p = 0.012 \)). Undergraduates were more successful in the explanation of the term CuSO\(_4\)-5H\(_2\)O(s) (\( \chi^2 = 26.380, df = 2, p < 0.000 \)).

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” (\( \chi^2 = 16.045, df = 4, p = 0.003 \)), “interaction” (\( \chi^2 = 9.818, df = 4, p = 0.044 \)), “valence electrons” (\( \chi^2 = 17.443, df = 4, p = 0.002 \)), “ionic bond” (\( \chi^2 = 15.028, df = 4, p = 0.005 \)), “CuSO\(_4\)-5H\(_2\)O” (\( \chi^2 = 11.679, df = 4, p = 0.020 \)), benzene resonance forms (\( \chi^2 = 11.503, df = 4, p = 0.021 \)), “\( \mu \)” (\( \chi^2 = 18.713, df = 4, p = 0.001 \)), “kg m\(^{-3}\)” (\( \chi^2 = 9.650, df = 4, p = 0.047 \)), “\( A = N(p^+) + N(n^-) \)” (\( \chi^2 = 11.806, df = 4, p = 0.019 \)).

These findings may be consistent with the Dunning–Kruger effect reported by Pajzicni 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 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

Zaokruzite tvrdnju koju smatrte ispravnom.

I. Benzin je derivat nafte. To znači da je benzin
   (1) lako hlapljiva tekućina.
   (2) samo jedan od mnogih dijelova nafte.
V. (3) Nuspojave smo mogli neutralizirati novim lijekom.
(2) Karbonizacija s ˇec´era temelj je proizvodnje slasnih
(1) Karbonizacija je nuzˇan proces u nastanku gazirane vode.

III. U kojoj je reˇcenici rijeˇc karbonizacija smisleno
(1) Karbonizacija je nuˇzan proces u nastanku gazirane vode.
(2) Karbonizacija drveta bijaˇse tolikih razmjera da je plamen
(3) Karbonizacija ˇceka temelj je proizvodnje slasnih
(4) Karbonizacijom bijelog braˇsa pod visokim tlakom

V. Ograniˇcenje (1) Slana c´e otopina neutralizirat c ´e trojku iz zalaganja.
(2) Moja petica iz znanja neutralizirat c ´e trojku iz zalaganja.
(3) Nuspojave smo mogli neutralizirati novim lijekom.
(4) Moja petica iz zalaganja neutralizira ˇce trojku iz znanja.

IV. U kojoj je reˇcenici rijeˇc neutralizirati ispravno
(1) Slana c´e otopina neutralizirat c ´e trojku iz zalaganja.
(2) Moja petica iz znanja neutralizirat c ´e trojku iz zalaganja.
(3) Nuspojave smo mogli neutralizirati novim lijekom.
(4) Moja petica iz zalaganja neutralizira ˇce trojku iz znanja.

V. Ograniˇcenje (1) Slana c´e otopina neutralizirat c ´e trojku iz zalaganja.
(2) Moja petica iz znanja neutralizirat c ´e trojku iz zalaganja.
(3) Nuspojave smo mogli neutralizirati novim lijekom.
(4) Moja petica iz zalaganja neutralizira ˇce trojku iz znanja.

VII. U kojoj je reˇcenici rijec’ 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
(4) Lopta je imala veliki efekt s obzirom na putanju kojom je

VI. U kojoj je reˇcenici rijec’ efekt ispravno upotrijebljena?
(1) Slana c´e otopina neutralizirat c ´e trojku iz zalaganja.
(2) Moja petica iz znanja neutralizirat c ´e trojku iz zalaganja.
(3) Nuspojave smo mogli neutralizirati novim lijekom.
(4) Moja petica iz zalaganja neutralizira ˇce trojku iz znanja.

III. U kojoj je reˇcenici rijeˇc’ efekt ispravno upotrijebljena?
(1) Slana c´e otopina neutralizirat c ´e trojku iz zalaganja.
(2) Moja petica iz znanja neutralizirat c ´e trojku iz zalaganja.
(3) Nuspojave smo mogli neutralizirati novim lijekom.
(4) Moja petica iz zalaganja neutralizira ˇce trojku iz znanja.

II. U kojoj je reˇcenici rijeˇc’ modifikacija smisleno
(1) Modifikacija kukuruza je dugo trajala, ali baˇse niˇsta
(2) Reˇci ˇcu ti broj mobitela kad se zgotovi modifikacija
(3) Zahtjevna modifikacija dijamanta izvedena je brusom od
titana!
(4) Osnovni cilj odgajatelja u vrtic´u ‘Centar grada’ jest

II. U kojoj je reˇcenici rijec’ efekt ispravno upotrijebljena?
(1) Slana c´e otopina neutralizirat c ´e trojku iz zalaganja.
(2) Moja petica iz znanja neutralizirat c ´e trojku iz zalaganja.
(3) Nuspojave smo mogli neutralizirati novim lijekom.
(4) Moja petica iz zalaganja neutralizira ˇce trojku iz znanja.

I. Slana c´e otopina neutralizira ˇce trojku iz zalaganja.

I. Modifikacija kukuruza je dugo trajala, ali baˇse niˇsta
promijenilo nije.
(2) Reˇci ˇcu ti broj mobitela kad se zgotovi modifikacija
posljednjih znamenki.
(3) Zahtjevna modifikacija dijamanta izvedena je brusom od
titana!
(4) Osnovni cilj odgajatelja u vrtic´u ‘Centar grada’ jest

XIII. Zagaˇdjenje je dokazano elementarnom analizom.
To znaˇci da je analiza bila
(1) najo ˇsnovnija.
(2) vrlo sloˇzena.
(3) kemijska.
(4) fizikalna.

XIV. U kojoj je reˇcenici pravilno upotrijebljena rijeˇc
proportacija?
(1) Bijaˇse mu malo pet proporcija ukusne orahnjaˇce; htio je
joˇs!
(2) Proporcije nagradne igre uvijek su istaknute na stranici
organizatora.
(3) Svaki ekonomist zna izraditi proporciju troˇskova za
slijeˇdeˇcu godinu.
(4) Proporcija njihovog vlasnisˇtva bila je oˇcita – svaki je
posjedovao ˇcetrтинu dionica tvrtke.

XV. Izradio je planarni prikaz njene kuˇce. To znaˇci da je izradio
(1) model.
(2) nacr.t.
(3) maketu.
(4) plan gradnje.

XVI. U kojoj je reˇcenici rijeˇc frakcija ispravno upotrijebljena?
(1) Frakciju lubanje zadobio je padom s motocikla.
(2) Frakcija je komplet koji su nosili muˇskarci u 19. stoljeˇcu –
frak i seˇsir, rukavice i stap.
(3) Ekstremna frakcija stranke ‘DPDPMO’ je izvela puˇc i
preuzela vlast.
(4) Frakcija je krkveni 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 najzavisnija je za dobar prosjek fakulteta.
4. Generalizacija će omogučiti precizan uvid u svaki od slučajeva.

XIX. U kojoj je rečenici riječ permanentni ispravno upotrijebljena?
1. Svaki flomaster s rupicama na kućistu, naziva se permanentni flomaster.
2. Permanentni je pritisak urodio plodom.
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 registru.
3. Nezbrinutoj djeci donirati će plisane medvjedice.
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.

XII. 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.

XIII. The pollution was proven by **elemental** analysis. 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.

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

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**References**


