OPEN ACCESS

ISSN: 2835-6764

DOI: 10.47378/2835-6764/AJSER:1000109
Bogdan E, et al. American J Sci Edu Re: AJSER-109

Research Article

American Journal of Science Education Research

Language Used During Chemical Problem Solving: An Explorative Analysis with Own Word Maps

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Citation: Bogdan E, Wolf K, Mika S, Waitz T (2023) Language Used During Chemical Problem Solving: An Explorative Analysis with Own Word Maps. American J Sci Edu Re: AJSER-109.

Received: Mar 10, 2023; **Accepted:** Mar 16, 2023; **Published:** Mar 21, 2023

Abstract

The present study contributes to research on language competencies in chemistry class and offers first approaches on how teacher trainees and students solve chemical problems using chemical terminology. The main focus of interest is the use of specific chemical terminology examined by a triangulation of three methods: own word maps, thinking aloud and interviews. The results reveal different individual approaches of language usage and techniques of creating own word maps. Furthermore, they confirm that specific terminology plays a role when solving chemical problems. This paper suggests a greater consideration of research on language competencies in chemistry class and contributes to the rating of own word maps as an instrument in chemistry educational research.

Keywords:
Own word maps, language usage, terminology, chemistry education

Introduction

Language is the main medium of chemistry classes; that means, acting in class is acting through language at the same time. Regardless of chosen teaching methods, specialized contents are always depicted, discussed, structured, applied, etc. by language [1]. Merely these facts and circumstances suffice and reason the relevance of the language issue concerning science teaching. However, compared to other areas of research and education in the field of teacher training, it is obvious that language is paid little attention to, exactly as in science in general, where lingual competences are perceived as peripheral [2, 3]. According to Leisen and Pietsch, natural science teachers may ask whether they have to consider terminology and language teaching in their courses besides technical content [4, 5]. The reason for this originates in the presumed difference between language and science classes which is based on institutional splitting of departments, faculties or consortia at schools or universities [6]. Supported by results of neurosciences, which localizes lingual and mathematic-scientific thinking processes in different brain regions [7], this precise division of tasks results in limited room for language studies and language promotions in science education. Bauer and Nase already stated a lack of chemistry educational research in lingual problems in chemistry class back in 1983 [8]. However, the role of language learning in science education seems to slowly come into focus of research. Whereas such topics as technical reading ability [9], communication structures in class [10] or chemical formulas [11] have already been investigated, linguistic problems in chemistry class lead to severe problems learning natural science subjects. An aspect which has been investigated almost exclusively in the USA is learning of scientific, technical language [12–14]. In contrast, research in learning scientific terminology has not been focused in depth. Nevertheless, scientific terminology acquisition and usage are major communicative competences in many curricula, e. g. in scholastic standards for lower secondary level formulated by German Ministers of Education and the Arts (see table 1, highlighted aspects) , Framework for K-12 Science Education or AP®-Chemistry Curriculum [15–17]. Competence in scientific terminology is required not only in direct confrontation with it in standards S4 and S5, but also in indirect references to subject-specialized text- and working forms.

No. of standard	Explanation
S1	Students investigate a chemical issue through different sources,
S2	choose topic-related and comprehensive information,
S3	examine the exposition in media regarding their subject specific correctness,
S4	describe, illustrate or explain chemical issues with use of technical language and/or by means of models and representations,
S5	figure out coherences between chemical issues and everyday experiences and deliberately translate technical language into everyday language,
S6	protocol the progress and results of research and discussions in an adequate manner,
S7	document and present the progress and results of their work appropriate to situation and addresses,

S8	argue in a technically suitable and consecutive manner,
S9	press their point regarding chemical issues and reflect objections self-critically,
S10	plan, structure, reflect and present their work as a team.

Table 1: Scholastic standards (S) for the communication domain in chemistry classes in order to achieve a secondary school leaving certificate (emphasis added) [17].

Acquisition of terminology in (chemistry) class is a large research area investigated in several studies [18–21], e. g. in relation to the mother tongue of students [21] or for teaching K-12 science [20]. The present study focuses on having a first look into the actual process of acting through language and describing a first attempt to facilitate the acquisition of chemistry terminology. An explorative study on the shown use of language in solving chemical problems was carried out using Own Word Maps (OWMs): Five chemistry teacher trainees (master of education program) and five 10th grade high school students (all were German native speakers) have voluntarily participated. Within this study, we focused on the following research questions:

a) Are everyday terms and/or chemical technical terms used in chemical problem solving?
b) How are given chemical technical terms integrated into the solution process?

Methods

In order to explore the use of language in solution processes, a triangulation of social-scientific qualitive methods has been chosen to investigate this domain. The triangulation of methods ensures a higher validity of made assertions.

For the problem-solving exercises, OWMs were used as a distinct form of term illustration based on Sumfleth and Tiemann [22]. OWMs provide the possibility to visualize the individual interpretation of terms and their relation. The tested task verbalizations of Sumfleth and Tiemann were used [22], whereas new pictures where chosen. Within the study, the participants had to describe a way from a picture A, an enlightened match, to a picture B, which showed corroded metal (see figure 1). The selection of both images provides a wide spectrum of redox chemical terms which can be integrated in the OWM including classical and expanded redox concept. To ensure that the participants are used to the method of OWMs, they initially worked on a probational task of another subject area.

Figure 1: Pictures used for Own Word Maps (top: probational task).

The unambiguousness of the pictures was well-tried in pre-tests. To additionally examine the integration-behavior of chemistry terms in their own procedure of solution, the participants were given fifteen chemical terms to fill into their OWM (integration test): *chemical reaction, electron release, electron acceptance, electron transfer, endothermic, exothermic, indicator, oxidation, proton, redox reaction, reduction, oxygen, acid, non-noble, combustion*. Sumfleth & Tiemann's tested task verbalizations were used again [22].

The second method used in this study is the method of thinking aloud [23]. All participants were asked to explain their thoughts while drawing their own word maps. According to Konrad [23], this method provides an insight into mental processes (introspection). As objectivity, reliability and validity of this method can be considered as low, gained information was only used additionally. After completing the task, the participants were asked to describe their task-handling again in a follow-up interview. This can be understood in the context of a delayed retrospective in order to investigate how participants solved the chemical problems depicted in the OWMs. At first, the participants were asked to reflect how they created their OWM. The following parts were focused on the usage of terms. At the end of the follow-up interview, their overall attitude to technical language acquisition was abstracted in order to gain information on their fluency.

Afterwards, all participants were marked with letters according to table 2 to ensure a clear presentation of results.

Teacher trainees					Students				
A.w	B.m	C.w	D.m	E.m	V.m	W.m	X.m	Y.m	Z.w

Table 2: Notation of participants.

The entries noted in the OWMs were counted and categorized in order to distinguish everyday language from chemical terminology (quantitative approach). To make the discrimination of everyday language from chemical terminology as accurate as possible, a research in an German chemical encyclopedia [24] and experts' assessment (five members of the department of chemistry and chemistry education, University of Göttingen) were combined. Finally, all notes were categorized into chemical terms, other terms and not assignable terms. To analyze the OWMs in a qualitative way, used terms were grouped into semantic fields. Moreover, different approaches which were visible in the OWMs were analyzed. To quantify these results, the number of ways, meaning the solution processes and dead ends put into writing by the participants, and the leaps between those processes were counted. The sound recordings of the method of thinking aloud and of the interviews were transliterated and analyzed. The design of the study is summarized in figure 2.

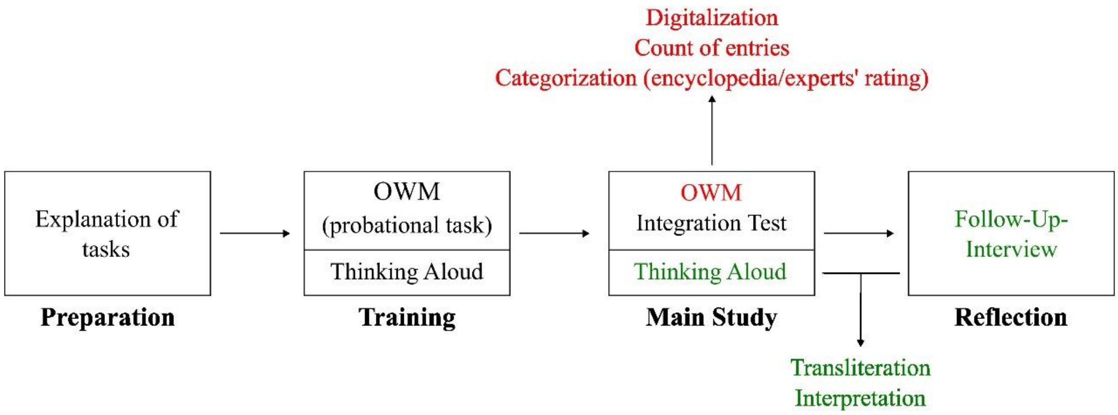

Figure 2: Four-Step-Design of the conducted study.

Results

The count of entries within the OWMs and quantity of used terms with and without multiple responses show distinctly individual differences in the elaborateness of working on the task. Table 3 shows the count of entries within the OWMs; it varies between 7 and 23.

	Students				
	A.w	B.m	C.w	D.m	E.m
Number of terms in OWMs	13	13	14	23	12
Number of terms with multiple responses	19	13	16	29	13
Number of terms without multiple responses, of it:	15 (100)	12 (100)	14 (100)	26 (100)	12 (100)
chemical terms	9 (60)	5 (42)	10 (71)	18 (69)	6 (50)
other	1 (7)	5 (42)	3 (22)	6 (23)	5 (42)
not assignable	5 (33)	2 (16)	1 (7)	2 (8)	1 (8)
	Pupils				
	V.m	W.m	X.m	Y.m	Z.w
Number of terms in OWMs	19	9	10	17	7
Number of terms with multiple responses	19	10	10	17	7
Number of terms without multiple responses, of it:	16 (100)	9 (100)	10 (100)	17 (100)	7 (100)
chemical terms	4 (25)	4 (45)	4 (40)	5 (30)	3 (43)
other	9 (56)	3 (33)	3 (30)	6 (35)	4 (57)
not assignable	3 (19)	2 (22)	3 (30)	6 (35)	0 (0)

Table 3: Evaluation of OWMs to extent and manner of term usage (in brackets: percentages).

Comparing the number of used words with and without multiple responses further, it becomes apparent that all teacher trainees and two students use terms repeatedly in their OWMs. A higher number of terms as compared to the number of entries in the OWMs of C.w, E.m, W.m, A.w and D.m is partly attributable to the reuse of terms in various entries. Counting and analyzing the words used in the OWMs shows that all participants use chemical terms. The number of chemical terms lies at 4±1 with students, whereas teacher trainees draw a very heterogeneous picture.

Students categorized a fourth to half of the used terms as chemical terms in their OWMs, students have by trend a higher percentage of 42% to 72%, but overall show greater interindividual differences. Comparing the number of terms which can be categorized as chemical terms, everyday terms or terms of other specialized fields (e. g. healthcare), the results reveal that two of the teacher trainees (B.m, E.m) and four of the students (W.m, X.m, Y.m, Z.w) have a balanced ratio of technical and everyday words; the number of terms in these categories differ at most by ± 1 term. Furthermore, it is obvious that the number of not-assignable terms varies strongly. These findings suggest that context and verbalization of OWMs partially do not suffice a database for unambiguous attribution. As a main aspect of a quantitative evaluation of OWMs, a very diverse individual dealing with the task is shown. For one, the participants differ in respect of quantity of entries and number of used terms, as well as their multiple responses. For another, they differ in their usage of technical language. By trend, the probed teacher trainees use more chemical technical terms than everyday terms, whereas students tend to show a balanced ratio between both categories. Nevertheless, there are great interindividual differences in both probed groups of teacher trainees and students. Therefore, it is not possible to derive any distinct hints, whether chemistry teacher trainees use more technical terms in their OWMs because of their advanced knowledge.

To further explore the use of language, the used terms were grouped into semantic fields. Although there are different term associations of participants, there are some fields found in multiple OWMs. These are everyday objects/everyday phenomena, corrosion/extractive metallurgy, chemical reactions/redox reaction/electrochemistry, chemical substance terminology/element terminology and environment/ climate. The category of everyday objects and phenomena was assigned with colloquial terms of various kinds. The field of the fire term is treated as a subcategory, since it occurs in all OWMs with at least one word which can be referred to the enlightened match in picture A. However, picture B tends to encourage the use of words out of the field of metal and corrosion. In almost every OWM, words of this field are found. Teacher trainees and students hardly differ in their choice of words within this category, merely in the word field of extractive metallurgy one student partly uses more accurate terminology like *iron smelting.* This is similar to the area of chemical reactions. By trend, there is a higher amount of redox chemistry terms found in the OWMs of teacher trainees than in the OWMs of students, but in most OWMs there is a more general paraphrasing than a precise explanation of the depictured chemical process.

An analysis of the use of terms shows some semantic fields which are mentioned by either only teacher trainees or students. Three of the teacher trainees associate *phosphorus* with picture A, even *sulphur* in one case, and state in the subsequent interview that they thought about the composition of the match first. This consideration is not found with students. Nevertheless, three students associate carbon dioxide with the burning match. Environmental and climatic terms play a big role in their OWMs, which stands in opposition to those of the teacher trainees. While they lay their focus on the chemical explanation of everyday objects and phenomena, the subject of environmental chemistry seems to be very popular with students, be it for environmental education or depiction in media. However, the quantitative usage of terms cannot be reliably investigated because of the small sample. The activation of different word fields entails that the participants use different solution processes to connect picture A and picture B. There are connections with extractive metallurgy, contact of metal and water or acid, oxygen and the term of oxidation and general principles of chemical reactions found. Solution processes differ in special knowledge and chemical language, which could be denoted as the quality of solution processes. Teacher trainees and students' phrase are on a colloquial, as well as a technical stage.

The evaluation of the OWMs showed not only differences in extent and use of language, but also in the adaption behavior of the participants. To unambiguously isolate processes from multiple associations for every term and looping, they were defined as polynomial chains of terms which do not end in the initial chain. The second feature, 'leaps', estimates the number of interchanges from one process to another. Calculational, the number of leaps has to be the number of solution processes minus one, since finishing of a process needs to be followed by a leap leading to a new starting point.

Due to counting of processes and leaps, two variant types of behavior in composing OWMs come into notice. On the one hand, there are those who handle the tasks in a linear manner and those who handle the task erratic. Those handling the task linearly associate terms as a term chain that they trace up until the end. Once they are finished with a chain, they either turn towards another term chain or end the task completely. On the other hand, the ones handling the task in an erratic manner starts a term chain, leap over to another chain and then start working on those they already started again. B.m, C.w, E.m, W.m, X.m und Z.w are considered linear adaptors, whereas A.w, D.m, V.m and Y.m are considered erratic adaptors (table 4).

	Students					Pupils				
	A.w	B.m	C.w	D.m	E.m	V.m	W.m	X.m	Y.m	Z.w
Number of processes	3	3	1	5	1	4	1	3	4	1
Number of leaps	3	2	0	5	0	5	0	2	5	0

Table 4: Adaption Behavior in composing OWM (highlighted white: linear adaptors; highlighted grey: erratic adaptors)

Linear adaptors participants have in common that the number of leaps is lower than those of processes, which shows that they do not come back to previously described processes. The number of formulated processes is relatively low. In over half those cases there is only one process formulated. This approach can be determined as very targeted. An example map of a linear approach is shown in the following figure 3.

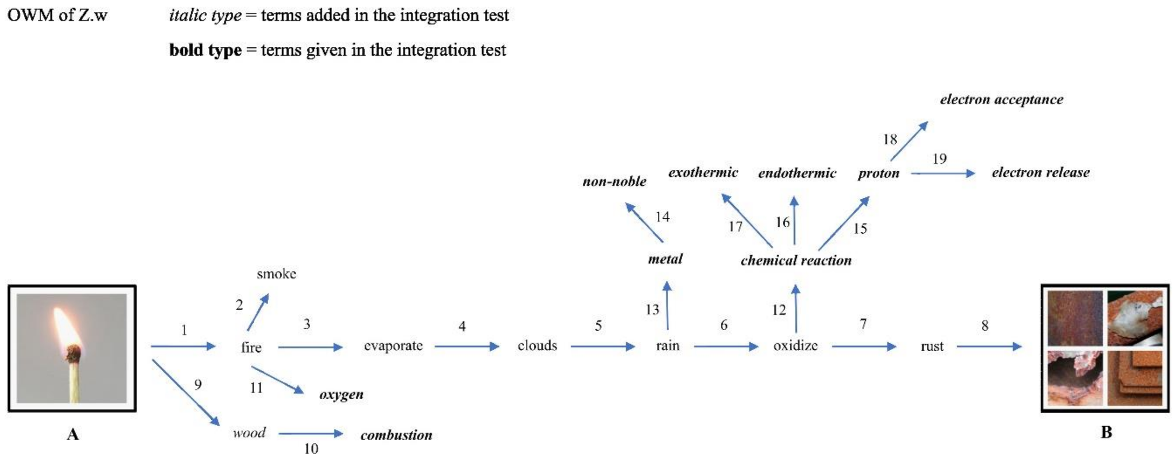

Figure 3: OWM of a linear adaptor (Z.w).

In contrast, all of the erratic adaptors leap at least two times between their conceptual processes. Compared to linear adaptors, a higher number of formulated processes is shown. Opposed to the strongly targeted behavior of linear approaches, erratic adaptors work on multiple processes simultaneously, therefore developing a bigger net of different terms which lets them appear more complex and elaborate than those of participants with linear approaches. An example map of an erratic approach is shown in the following figure 4.

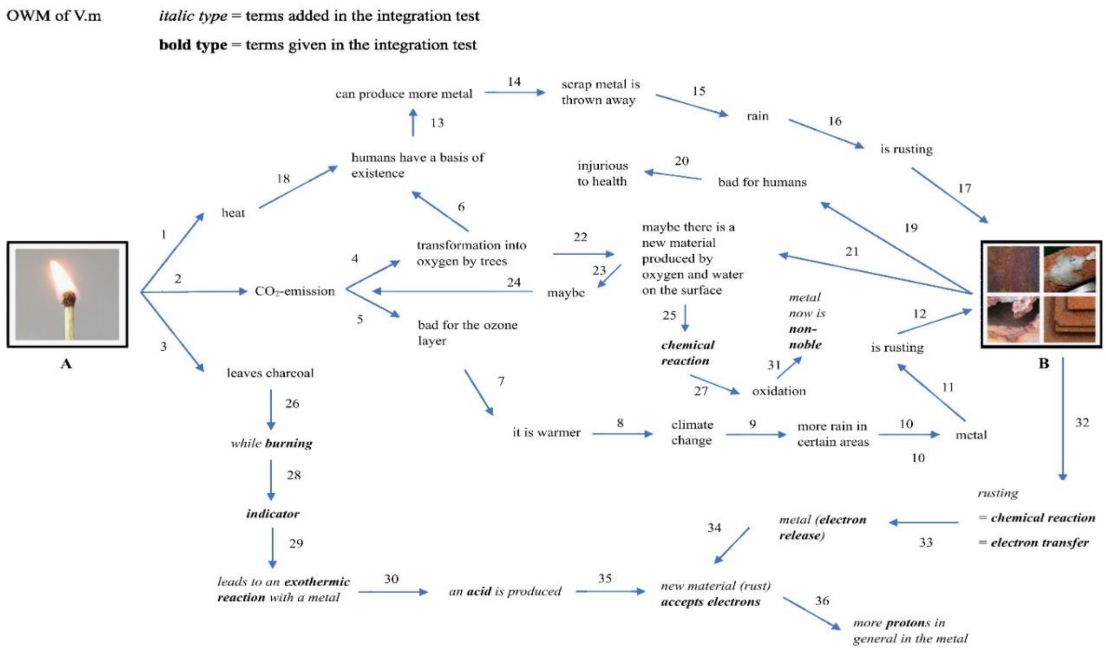

Figure 4: OWM of an erratic adaptor (V.m).

Comparing these results with the use of language analyzed above and the word fields or solution processes, no distinct congruities that could deduce a hypothesis of a causal coherence between adaption behavior and acting through language were found.

This does not leave out the possibility, that adaption behavior in composing of OWMs and the use of technical terminology could be linked. To what extent – besides further possible factors like interconnectedness or application of different adaption strategies - the different adaption behavior can also be attributed to the availability of technical words needs to be the object of further research.

In the integration test, the participants were asked to integrate fifteen chemical terms into their OWMs. The results are shown in figure 5.

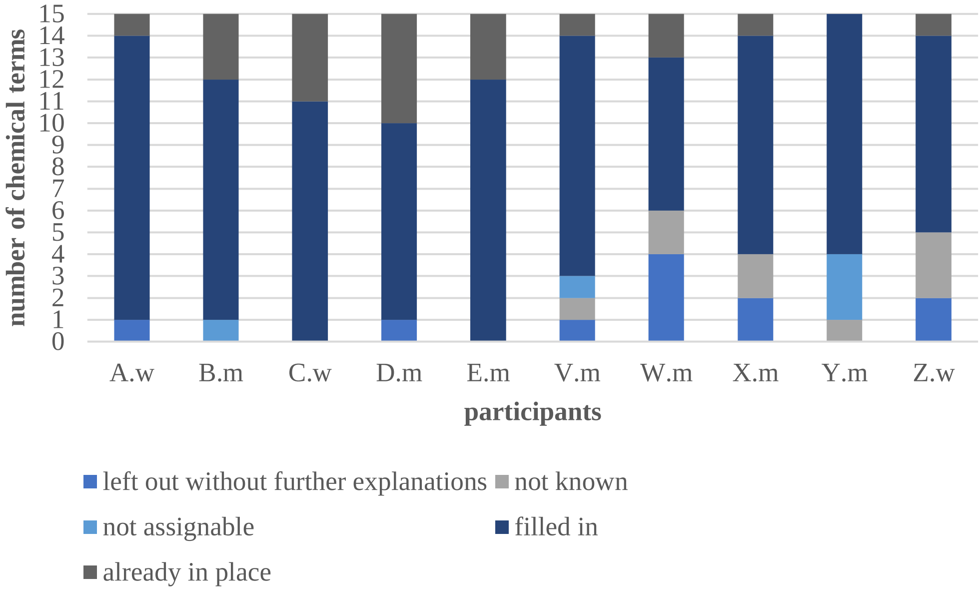

Figure 5: Results of integration test (sorted by participants).

Comparing the results, it came into recognition that at least one of the words to be inserted was already existent in the OWMs. Maximally five of the given expressions were already used. The rest of the words were either filled in, marked not assignable or not known, or were left out without further explanations. Whereas all words were marked known by the teacher trainees and maximally one was left out in their OWMs, the students integrated maximally twelve of the given terms and marked at least one unknown.

The evaluation also shows that the integration of terms is not only depending on study participants but on the given words (figure 6).

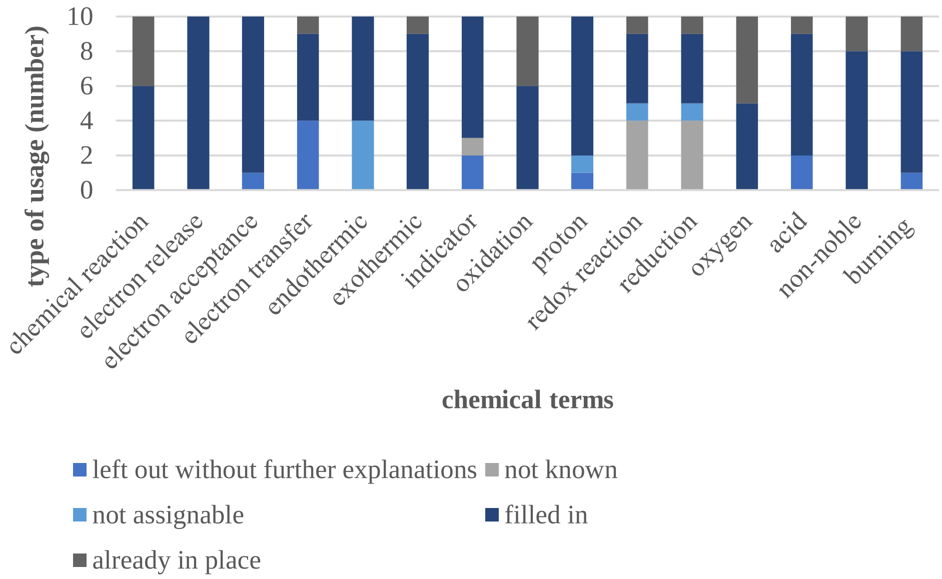

Figure 6: Results of integration test (sorted by terms).

The terms *chemical reaction, electron release, exothermic, oxidation, oxygen* and *non-noble* were integrated by all participants. Out of these words, *chemical reaction, oxidation* and *oxygen* were most frequently already filled in with only four to five alterations, which points to a closer overall connection of these terms with the subject areas by the participants. This hypothesis is supported by the fact that all participants were able to fill in the terms after they were given to them.

As it can be seen in the quantitative aspects, it seems possible that existent expert knowledge influences the behavior in filling in given terms. Teacher trainees integrate more technical terms and do not show any uncertainties in the transcripts of thinking aloud and the interview as was the case with some students. A good example for this is the conceptual pair *exothermic – endothermic*. Three of the students stated to confuse these words, two tried to derivate a lingual connection over the meaning of Greek prefix *exo-*. Additionally, one participant posed a seemingly memorized definition. Another strategy of compensating lacking expert knowledge or difficulties with recalling same knowledge was assortment-based speculating over terms. Lacking expert knowledge about the depicted chemical processes was replaced by i.e. conclusions and speculations. One of the students assumed due to the given term *acid*, that acid emerges from corrosion (V.m.). This shows that an evaluation of the integration test without additional data in which the participants explain their mapping would be error-prone, since the meaning or correlation with chemical processes of some of the words to fill in is not totally clear to the participants.

Alongside the expert knowledge, the structure of own OWMs has a big influence of the integration behavior, since technical terms are just filled in if connecting factors are seen. As can be seen in the example of *endothermic – endothermic* again, the term *endothermic* is filled in a lot less than *exothermic*, although the participants could all assign them to the topic of *chemical reaction*. It was frequently stated that they could not find any connectivity in OWMs, since they missed a definite example of endothermic processes. The structural factor of OWMs seems to be closely connected to individual integration behavior of study participants. Preferences and manner of attribution, as well as individually attached importance of given terms in connection to own solution processes can be counted for that. The participants state partially that a term does not occur in their solution process and is therefore not integrated. The integration of terms into OWMs is strongly dependent on the previously made entries and the relevance that is ascribed to the term in connection to the depicted reasoning. Missing integration is therefore occasionally attributed to mentioned other factors.

Lastly, the given terms play a big role in the integration of terms. Terms marked by a wide term range or distance of contents were by trend felt to be toughly capable of being integrated. An example for a term with a wide term range is *chemical reaction*. This term is either integrated nonspecifically, as superordinated term or labelling of example reactions. Indecisiveness and integration problems because of the wide term range were often expressed. Terms having no connection to the depicted processes were likewise marked difficult. An example for this taken from the given study is the term *indicator.*

This little sample alone, which can clearly not provide an overall picture, shows that integration of technical terms into OWMs is influenced by various factors and cannot be explained only by lingual competences.

Discussion

The present study focuses on manner of language use while solving chemical problems, with special allowance on technical language as dimension of description. Quantitative evaluation of the OWMs shows great interindividual differences in handling extent and use of terms of participants. In respect of analyzing the use of technical language, it can be concluded that chemical terms are used in solving problems in all OWMs, whereas the extent of technicality varies. Nevertheless, technicality seems to be part of the participants' natural language use in solving chemical problems. While the qualitative analysis shows that most solution processes do not describe chemical processes and that used terms are therefore part of a wider term field, a tendency to use more exact technical terms can be seen with the students. A strong bipolarity - all students being more competent because of their higher qualification -cannot be identified. Teacher trainees and students both used every day and technical explanatory models in solving problems. The results from the integration test provide a rudimentary explanation for the group of students. The integration test shows that students partially have acquired a limited term extent, for example with the term of *oxidation*, which features parallels to the beforementioned American research results [12–14]. Furthermore, they displayed a limited terminology. However, the small sample limits the validity.

At this point, it has to be mentioned again that the students showed strong interindividual differences in language and task behavior and they seem to vigorously distinguish in their term acquisition. This stands in opposition to the teacher trainees, who knew all given terms and were able to connect them with scientific ideas. Therefore, lack of detailed scientific solution processes, for instance at particle level, show that participants had no urge to phrase those processes in such a manner without explicit requests.

Another result of the integration test is that the integration of technical terms is dependent on various factors. Thereby, present expert knowledge, connecting factors in the personal OWM and preferred integration behavior, as well as extent of terms and closeness to depicted chemical processes were worked out of data material. The technical terms that were to be integrated were partially seen as addition to the own solution processes, but partially also as unhelpful to the own chain of thought. Retrospectively to the carried-out research it can be stated that not only different words but different terms than those given by the integration test are activated by the study participants. Furthermore, a limitation of validity of the basic assumption, stating that quantity and quality of term classification could form assumptions about term interconnectedness of the participants, is to be recognized, since terms were, despite their assignability, not necessarily used within the integration test or respectively used without expert (term) knowledge. Reasons for this are, for instance, that the study participants missed connecting factors in OWMs or thought of terms being irrelevant for their described solution process or compensating strategies to accomplish the task. This is to be especially considered in the quantitative evaluation, since the integration coherence does not emerge obviously without further data of verbalization.

The use of OWMs as an instrument of research constitutes terminology competence in a specific manner. Due to study participants concentrating on the solution process and deliberately concealing the actual interest of research before carrying out the study, a preferably natural use of language was compiled, but many other aspects of chemical technical competence were left out in the dark.

Conclusion and Outlook

As stated before, technical language development in chemistry classes is paid too little attention in teaching practice and subject-didactic research. The study shown here took a problem with a great influence on everyday life, in order to formulate ways of solving problems in a technical, as well as a colloquial manner. It is supposed to make a contribution to raise awareness of the problem and lay bases for further research on language use while solving chemical problems. Separate from OWMs, methods and instruments to describe and measure technical language acquisition are missing. The development of those needs to be in interest of science educational research in order to develop a sensitivity for the meaning of chemistry terminology in chemistry education, and to further develop classes in this area based on research arguments.

An important question for further research is whether teacher trainees and students differ quantitatively in their usage of chemical language, which could not be investigated in this study because of the small sample.

The overall goal is to break up the estimated difference between language and science classes: Language should be seen as an important, not impeding part of scientific education.

Importance of research

- Contribution offers first approaches on how teacher trainees and students solve chemical problems with language.
- Attitudes towards the application of language are investigated using the methods of thinking aloud and follow-up interviews. Furthermore, the study is aimed at initiating further research on this question.
- Paper contributes to the rating of own word maps as an instrument in chemistry educational research.

All authors agree to the publication of this manuscript.

Acknowledgements

We thank Stephanie Mika for conducting the study.

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