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Vernacular Misconceptions in Teaching Science – Types and Causes

Marcin M. CHRZANOWSKI[1], Wojciech GRAJKOWSKI[2], Szymon ŻUCHOWSKI[3], Krzysztof SPALIK[4], E. Barbara OSTROWSKA[5]

[1] Assistant Professor, University of Warsaw, Faculty of Biology, ORCID ID: 0000-0003-1109-4236
[2] Assistant Professor, Educational Research Institute, Warszawa-POLAND
[3] Executive Editor of the *Polish Libraries* journal, National Library of Poland, Warszawa-POLAND
[4] Full Professor, University of Warsaw, Faculty of Biology, Warszawa-POLAND, ORCID ID: 0000-0001-9603-6793
[5] Assistant Professor, Educational Research Institute, Warszawa-POLAND

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ABSTRACT

The aim of this study was to identify, classify and describe different types of vernacular misconceptions assessed with the items used in a study named *Laboratory of Thinking,* Diagnosis of Science Education in Poland. We provide an outline of contemporary conceptual change theories and establish a typology of misconceptions where it was distinguished as amphibological, pseudodeictic, hypernimical-hyponimical and contextual ones. The vernacular misconceptions arise when students' experience problems with the usage of certain scientific language phrases and they may appear in people of all ages, professions and backgrounds. Selected items, together with their detailed description are discussed as well as the possible influence of misconceptions on the students' learning process.

Keywords: Vernacular Misconception • Misconception • Conceptual Change Theory • Science Items • Science language

INTRODUCTION

Prior knowledge, conceptual change and misconceptions

According to Resnic (1983), one can say that students do not come to school as blank slates and have some initial conceptions that influence the didactic process. Clarck (2012) pointed out that initial conceptions may be dynamic or structured, explicit or implicit. Several theories have been proposed to account for the transition from common-sense image of the world and phenomena it to a scientific understanding of them. This transition is often referred to conceptual change which can be defined as

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Corresponding author e-mail: mm.chrzanowski@uw.edu.pl

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learning in which pre-instructional conceptual structures of the learners have to be fundamentally restructured to allow students to acquire science concepts (Duit and Treagust, 2003). The notion of conceptual change may cover several meanings as exactly stated by Scott, Asoko and Leach (2007). Conceptual change can be perceived as the *process* of learning or as its *products*; it may mean *exchange* of concepts or their *modification*, *addition*, or *altering the relationships* between them. Finally, conceptual change may be seen as the *process of using strategies* to bring children's thinking in line with scientists (Agiande, Williams, Dunnamah, Tumba, 2015).

In recent years, two approaches have been prevalent related to the nature of conceptual change: the *knowledge-as-elements approach* (diSessa, 1988) and the *knowledge-as-theory approach* (Ioannides and Vosniadou, 2002). DiSessa (1988) describes conceptual change as resulting from the dynamic, mutable interaction of loose, mutually independent basic conceptions which called as *phenomenological primitives* (abbreviated *p-prims*). Vosniadou, in turn, argues for a model that postulates the existence of complex and stable theoretical structures which the learner perceives encountered phenomena. While some researchers emphasize their commonalities, these models are often strongly contrasted with each other and presented as far as deeply contradictory at least their significant instructional implications are concerned (Brown, 2010). From the implications and resulting applications, one of the descriptions of the conceptual change is the identification of the learner's prior misconceptions and "fixing" them through exchanging them or adding new conceptions that are more fruitful, plausible and intelligible (Özdemir and Clark, 2007, Chi and Roscoe 2002).

These pre-instructional conceptions have been named differently by various authors: *alternative conceptions* (Driver and Easly, 1978), *children's science* (Gilbert, Watts and Osborne, 1982), *personal knowledge* or *spontaneous knowledge* (Pines and West 1986), *misconceptions* (Helm 1980), and *preconceptions* (Clement, 1982; Clement, Brown and Zeitsman, 1989). Clement (1993) later distinguished between *preconceptions* as any prior knowledge (correct or not) and *misconceptions* as solely the sort of knowledge that is erroneous. Similarly, Skelly (1993) defined misconception as a mental representation of a concept that does not correspond to the currently held scientific theory. Therefore, misconceptions and preconceptions should be distinguished from plain and absolute lack of knowledge because the latter does not cause problems obviously addressed to conceptual change– that there is no need to undo or redo an incorrect framework which does not exist and is not widespread (Leonard, Kalinowski, Andrews, 2014). According to Page (2012), partially correct conceptions (i.e. those that are not entirely wrong and can be used in teaching) may be called as *alternative frameworks*, *naïve ideas*, or *children's ideas*.

The distinction made by Clement (1993) is going to be followed in the present article to avoid terminological confusion and the term *misconception* will only be used for those of pre-instructional conceptions that are not conform with up-to-date scientific theories. Thus, the term misconception is not actually going to refer to the misconceptions of Vosniadou's more specific view.

Walt (2011) stated that hardly anyone is certainly free of miscomprehensions, misperceptions or misjudgements that result from the usage of language. As Page (2012) says, these may be related not only to science but also to virtually all aspects of life such as religion, interpersonal relationships, history or simple housework, and may be found both in students and in teachers, regardless of their academic achievement. In a review article, Tippet (2010) stated that misconceptions may be considered as essential and unavoidable features of learning. Moreover, İnciser (2007) adds that misconceptions display noticeable consistency throughout the populations of the world.

Misconceptions may be divided in two ways according to their origin or to their functional type. According to Skelly (1993), they may originate from personal experience and institutional instruction. The functional type can be distinguished as *non-scientific beliefs*, *conceptual misunderstandings*, *preconceived notions*, *factual misconceptions* and *vernacular misconceptions* as classified by the Committee on Undergraduate Education (1997).

Johnstone (1984), Bodner (1987) and Sirhan (2007) stated that the principal sources of misconceptions are overloading the learner's short-term memory and wrong mental strategies (teaching with the use of algorithms and hastily covering too much material). In addition, Glaser (1984), Sweller (1988) and Lukša (Lukša, Radanoviš, Garašiš, Sertiš Periš, 2016) added that problems of conceptual learning may be due to going on to problem-based activities before properly internalizing the content , standard student epistemology, sources related to prior knowledge, mismatch of the cognitive demands of the subject matter with the developmental level of the learner, or language-related problems.

Language confusion

Communication is indispensable for transferring knowledge and language has a vital importance for science literacy as a means for communication. The language is used to convey procedures, inquiries and understandings to others in the form of written and spoken communications. As Yore (2003) observes, mathematics is not the exclusive language system of science. Both in scientific research and in teaching science, other representations are useful or even necessary such as analogies, metaphors, symbolic thinking and valid terminology which is often complex. The very language of science is not to be confused with everyday speech (natural language) as it is artificial and aims at monosemy. The vocabulary used for scientific purposes differs considerably from its everyday use, where notions may have numerous and often contradictory, meanings that depend strongly upon the situation (Sirhan, 2007). Though ambiguousness and equivocality may arise as particular specialties have their idiosyncrasies, there are certain standards of communication among scientists as pointed out in the members of Association for Science Education chat summary (Association for Science Education chat summary: What misconceptions do students have in science? 22.06.2011). The discrepancy between the natural language used in everyday life and that used in science classes causes problems that significantly impede the teaching process.

A definition of the vernacular misconceptions may be made according to Page (2012) who perceives it as the result of language confusion where mistaking everyday speech lexemes for scientific terms leads to erroneous interpretation of phenomena. This sort of misconceptions is particularly interesting since it is situated somewhere in between experience-based sources and instructional ones. The study of different authors (Champagne, Klopfer and Anderson, 1980; Linn, 1980; Glaser, 1984; Green, McCloskey and Caramazza, 1985; Sirhan, 2007; Kocakülah & Kenar Açil, 2010; Ezquerra, Fernandez-Snachez, Magaňa & Mingo, 2017) proved that the vernacular misconceptions stem not only from the fact that children acquire some vocabulary and (mis)representations in their childhood (at home) but also from textbooks and terminology use of teachers without being aware of different students may differently understand a concept or some students may not be able to face with the difficulties of the subject matter content as far as the vocabulary and syntax are concerned (Çobanoğlu & Şahin, 2009).

The vernacular misconceptions include problems with vocabulary and symbols as well as analogy and metaphor used in the subject matter. One of the difficulties related to terminology in teaching and learning science is that normally a learner is supposed to acquire not only a considerable number of new words but also the whole concept behind them and how they work in a context which are often abstract and in mutual relationships. Moreover, teachers tend to overestimate ability of students to understand in addition correctly and knowingly use the vocabulary. Some of the teachers unconsciously mislead students through replacing strict scientific terms excessively by everyday speech expressions. Another issue is the multiple-level representation of symbols in science. For instance, one symbol may be used for different purposes by different disciplines or even within one discipline (e.g. the letter "N" may stand for "North" in earth science, "nitrogen" and "normality" in chemistry, "newton" in physics) whereas one concept may be represented with different symbols (e.g. "energy" that is written as "E", "Q", "T" or "U" etc. depending on the context).

The analogies and the metaphors may be very helpful in teaching, but sometimes they bring more problems than they solve. Einstein is believed to say that everything should be made as simple as possible but not simpler while it is often the case that metaphors conceived to make things easier are more complex than the problem itself. On the other hand, the "seductive power" of analogy makes many people neglect the important differences while underlining the similarities. This has considerable impact on language structures that are established in the way the students think and speak about the natural phenomena. The metaphors are also perceived as tools offering a link between emotion and cognition, because they encourage learners to think more creatively without stick into rigid theories (their preconceptions included). However, this is only recommendable when the metaphor helps the explanation and does not replace it.

METHODS

The studies on misconceptions of students may improve our understanding of the reasons behind the difficulties that they experience in learning science. The present paper is meant to show some of the tools used in the *Laboratory of Thinking* study and the student results achieved in it. Sources of the common vernacular misconceptions were analysed and discussed which appear both in Polish and in other selected languages. Ways of tackling this problem was suggested based on findings and on literature review. The paper focused on:

- identifying the items that assess misconceptions among those used the *Laboratory of Thinking* study,
- distinguishing the items that assess vernacular misconceptions, and
- conceiving a typology of misconceptions related to the use of language together with discussing exemplary tools that illustrate them.

a) Research designing

The long-term study *Laboratory of Thinking – Diagnosis of Science Education in Poland* has been conducted by the Science Section, Educational Research Institute, Warsaw, Poland. Its aim was to examine the level of skills and scientific knowledge of the ISCED2 level (*gimnazjum*) graduates taught according to the new science curriculum introduced to schools in 2009. The findings of the study help to support teachers' work according to the recently changed curriculum. The study was not focused on students' misconceptions, nevertheless a part of the items used in it were clearly useful in tracking misconceptions.

Not all the items discussed in the present paper were used in the main study but only during the item preparation stage (the field trial). However, the qualitative information about misconceptions found in their results seemed so significant that it was decided to disclose them and analyse their outcome together with the items that did appear in the main study.,

b) Study group

The long-term study *Laboratory of Thinking* is composed of four cycles. From Table 1, it can be seen that over 7,000 students (having completed ISCED2 stage) were examined in the first two study cycles and in the fourth one and– another 14,000 in the third cycle (over 7,000 as in the first, second and fourth cycle and at the same time another group of more than 7,000 having completed the first year of ISCED3).

Table 1. *Number of schools and students assessed during each cycle of Laboratory of Thinking study*

No. of study cycle	1	2	3		4
Year of the study	2011 / 2012	2012 / 2013	2013 / 2014		2014 / 2015
No. of schools	180	180	180		180
No. of students	7700	7400	14000 7000	7000	7000
Level of education	ISCED2 level	ISCED2 level	ISCED2 level	After 1st year of ISCED3 level	ISCED2 level

The student samples were random and representative. For example, they reflected the proportions of students in the three types of schools in Poland (Table 2).

Table 2. *Different kind of schools at ISCED2 and ISCED3 level in terms of shortened characteristics of the educational stages in Poland*

Polish term	ISCED level	grade numbers	students' age	English term
Gimnazjum	2	7, 8, 9	13-15	lower secondary school
Liceum ogólnokształcące	3	10, 11, 12	16-19	secondary general school, comprehensive secondary school
Technikum	3	10,11,12	16-20	secondary technical school
Zasadnicza szkoła zawodowa	3	10,11,12	16-19	secondary vocational school

The sample consisted of 180 upper secondary schools and was stratified with respect to the type of school (basic vocational, technical secondary or comprehensive secondary), the capacity of the school (number of students in the first grade), the location of the school (countryside, town under 5,000, city 5,000–100,000 or city over 100,000 inhabitants), female to male student proportion (over 80% boys, over 80% girls or balanced) and whether being a state-operated or a private school.

c) Data Collection Tools

In each cycle of the study (year by year) a paper-and-pencil test was composed of 208 items that were used in each of the four science subjects (chemistry, physics, biology, and geography). 52 items were included for each of the subjects. About 60–80% of them were linking items, i.e. items that are repeated every year, and thus have to remain confidential. The items were arranged in 16 test versions in a way that both the difficulty level and the time needed to solve each version were similar.

Data collection tools for the study were prepared during workshops organized by the Institute of Philosophy and Sociology, Polish Academy of Sciences, in the years 2008–2010. The items were conceived individually by specialists from specific science groups (biology, chemistry, physics, and geography group), and then in several science groups of several people each headed by a subject leader.

The item preparing process (Figure 1) involved multiple reviews by academic specialists and a field trials performed on random student groups as well as interviews using the cognitive laboratory assessment (verbal probing technique as described by Willis, 1999), when needed. Details of the methodology can be found in the *Laboratory of Thinking* extensive study final report (IBE, 2012).

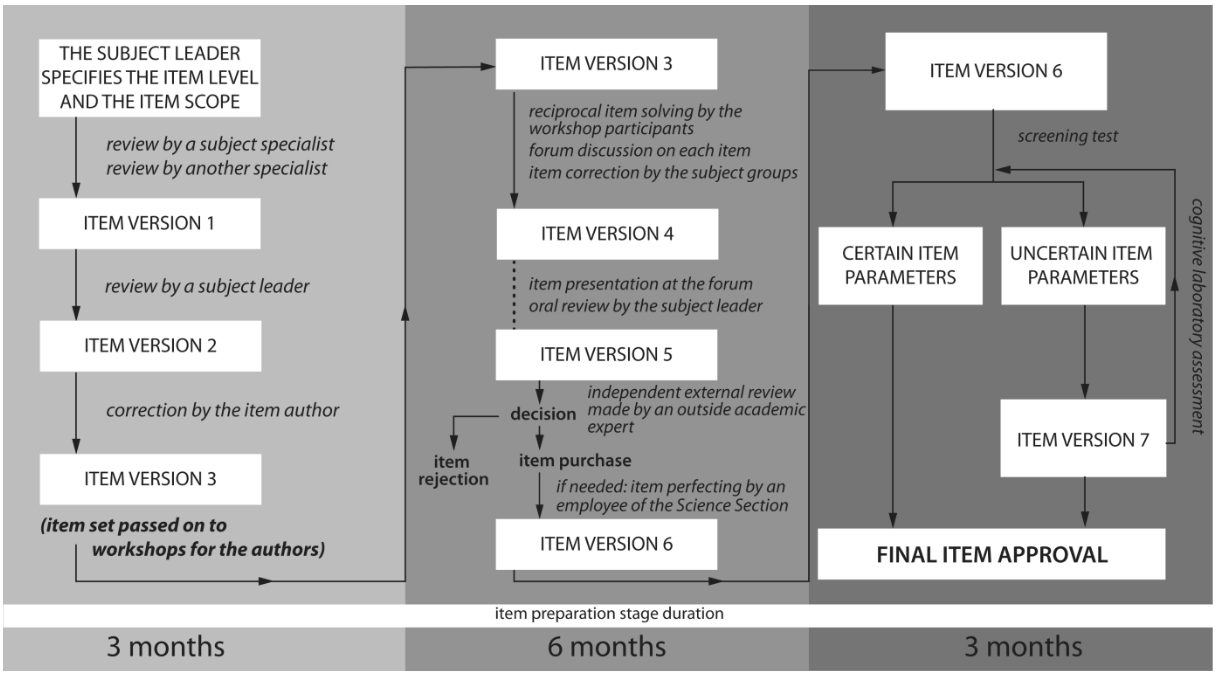


Figure 1. Stag*es of preparing cognitive items for* the Laboratory of Thinking *study (Chrzanowski and Ostrowska, 2018).*

According to the academic recommendations of DeBoer *et al* (2008), these tools were pilot-tested in screening test in 2010 on a representative sample of 120 upper secondary schools (on ISCED2 graduates) to profit from feedback and enhance the validity of the inferences. The results were assessed with the use of the Classical Test Theory (CTT), and the Item Response Theory (IRT). More information about items used in *Laboratory of Thinking* may be found in the study of Chrzanowski and Ostrowska (2017).

In the present paper, the student results are analysed with regard to four exemplary items conceived as representative of four different vernacular misconception types. For each item, a chart was prepared in which students were divided in eight groups depending on their score obtained for the whole test.

Subsequently, the average score for every item was checked in each octile groups. The items were A Cloud over the Cup, Birch, Moss and Fungi, Gas Boiler, and The Beetle and the Potato. All the items in the study were various types of close-ended questions such as multiple-choice, true or false, two-tier, and matching questions. Then, a set of interviews was carried out to track the way how the students reach the answer.

The interviews using verbal probe technique (Willis, 1999) were performed on selected students to track the possible reasons for misconceptions. Twelve students were interviewed for each of the three assessed items. They were ISCED2 seniors (normally aged 15–16) right before the final external examination who had completed the whole curriculum for that stage and so were familiar with all the content covered by the items. They came from four schools from the Mazovian Voivodship (randomly chosen by the publication authors from the schools that took part in the *Laboratory of Thinking* study). The students were selected by their teachers to fit in one of the three categories: *gifted but not diligent*, *gifted and diligent*, and *not gifted but diligent*. In that sort of study, it is essential that the students should be communicative. Thus, the selection had to be made by their teachers who knew the students best. Consequently, there were boys and girls in each of the groups, but their numbers were not equal. It is worth mentioning that all the items selected for the whole *Laboratory of Thinking* study had preliminarily been assessed with the Differential Item Functioning (DIF) method to avoid gender-related differences in abilities in members of separate subgroups.

Each interview lasted at around 1.5 hour and was recorded. To begin with, the student solved a test of several close-ended questions in science subjects including the biology, chemistry, physics, and geography. To complete this task, the student had as much time as he or she needed and additionally could write down a commentary to each of the items. Then, he or she was asked for questions about the school subjects they preferred and the reason behind it. General and item-specific questions were asked for each of the items. The questions are found in Appendix 1.

FINDINGS

Based on our study, it was presented here the content and analysis of students' answers to the items that are representative of four different types of vernacular misconceptions. Possible reasons for those given misconceptions stem from the use of language itself and occur not only in Polish but also in other languages.

a) A word with two different meanings in scientific and every-day context

The presented item *A Cloud Over the Cup* was used during the field trial but was not part of the *Laboratory of Thinking* main study. It was implemented on a representative group of 208 students from 20 classes of lower secondary schools in Poland. The item was as follows.

Analyze the picture and complete the sentence choosing the correct answer. Justify your choice.

(1) Over the cup of hot coffee there is a ‘cloud’ of
A. water vapour.
B. droplets of water.

(2) Justify your answer.
A. Water evaporates at 100 °C.
B. Water vapour is a colourless and odourless gas.

Percentages of student responses are given in Table 3. The correct answer to both parts of the item was given only by 8.17% of students.

Table 3. *The students’ (n = 208) responses to the item A Cloud over the Cup*

Answers	Students’ choices
(1) A. water vapor.	83.7%
(1) B. droplets of water.	**14.4%**
No answer	1.9%
(2) A. Water evaporates at 100 °C.	40.4%
(2) B. Water vapor is a colorless and odorless gas.	**50.5%**
No answer	9.1%

* The correct answers shown in bold.

The main aim of the item was to verify if there is a vernacular misconception among students that the cloud can be seen over the cup containing a hot beverage is water vapour. Such a misconception might result from the fact that the students confuse the everyday-speech meaning of the word vapour or steam (tiny droplets of liquid water in the air) with its scientific denotation (water in gaseous state, without colour and smell).

About a half of the students gave the correct answer in the second part of the item, which may mean that they had memorized (learnt by rote) the fact that water vapour is a gas that can neither be seen nor smelt. However, at the same time the answers to the first part of the item show that this knowledge is “inert”. For example, it has not been internalized. This means that students are able to remember and recall the properties of water in liquid state, but do not actually understand what it mean in “real life”.

Another problem is that common experience may also be misleading. It is fully acceptable to call the cloud that comes out of a kettle or an iron “steam/vapour” in everyday life, whereas this term has a narrower and precise meaning in science. This is partly because whenever a gas is to be represented, it is usually depicted as a cloud in media, comic books, cartoons etc., even it cannot be seen in real. When the words “vapour”, “steam” or “gaseous” (regardless of the language we speak: French *vapeur*, Spanish *vapor*, Italian *vapore*, German *Dampf*, Russian пар “*par”*, Polish *para*, or the Japanese 蒸 “jyou”) typed into a browser, it provide us with images of clouds in the sky, fumes coming out from chimneys or white cloudlets bursting from kettles, cooking pots, steam-cooked dishes or even a water pipe. Likewise, such images is often come across in science/chemistry/physics textbooks.

Although the curriculum for teaching science and chemistry underlines the fact that students should be acquainted with the phenomena of water phase transition both theoretically and empirically, it turns out that what students think about water is full of contradictions and inconsistencies.

The analysis (Table 4) has shown that 35.1% of the students chose (1)A and (2)A, i.e. “water vapour” and “water evaporates at 100 ºC”. The students adhere to safe (and not always relevant) definitions and clichés instead of trying to solve the specific problem. The most frequent (41.83%) combination was (1)A and (2)B, i.e. “water vapour” and “water vapour is a colourless and odourless gas”, which are conspicuously contradictory, as the students state that what they see above the cup is invisible water vapour. Only 4.81% of the students chose (1)B and (2)A, which probably stems from the fact that if they do not know what to choose and they opt for what seems more familiar (“water” and “100 ºC” make the most people think immediately of boiling water).

Table 4. *Students' answers cross-tabulation*

		2nd answer	
		A. Water evaporates at 100 ^{0}C	B. Water vapour is a colourless and odourless gas
1st answer	A. water vapour	A, A 35.1%	A, B 41.83 %
	B. droplets of water	B, A 4.81 %	**B, B 8.17 %**

* The correct answer marked in bold.

The interviews confirmed our assumption that the knowledge which the students have is incomplete, fragmented and often inconsistent. Some of the interviewees' beliefs are listed in below.

- Water vapour does not have to (or even cannot) be colourless, and may be grey or white;
- Water vapour makes the students think not only of fog, dew or clouds (in the sky), but also of smoke, fire (of a building), bonfire or more generally of diffusion and cloud of condensed steam;
- Glass, nail polish or water can be colourless but still cannot be invisible. So, water vapour may be colourless and visible (as a white cloud) at the same time (which suggests some of the students do not understand the notion of colourlessness);

- Water vapour may sometimes be visible and sometimes invisible depending on the conditions;
- Droplets are “something bigger such as raindrops”, while “water vapour are tiny droplets in real”.

Exemplary verbal probing interviews data are gathered in Appendix 2 (transcribed verbatim).

b) A name suggesting that association is stronger than it really is

The following item, “The Beetle and the Potato”, was administered to 1934 middle school (ISCED2) graduates as a part of the first cycle of the study *Laboratory of Thinking*. Subsequently, the item was published on a website dedicated to educational purposes and therefore it could no longer be used in the next cycles of the study. The item is shown below as it was presented to the students. The frequencies of their responses are given in Table 5.

Originally, Colorado potato beetle lived only in North America in the Colorado state area. Interspecies relationships existing in that ecosystem kept the beetle population size at a constant level. Everything changed when humans brought a new plant to Colorado. This was the potato, native to South America from thousands of miles away. In the early 20th century, the beetle was brought to Europe with a shipment of American potatoes. Today, both the plant and the insect that feeds on it are found almost everywhere in the temperate climate zone of the Northern Hemisphere.

Using the information from the text, decide whether the following statements are true or false.

	Statement	True or false?
1	Even though people consider the Colorado beetle a pest today, originally it fulfilled an important role. It regulated the size of the potato population.	☐ True / ☐ False
2	Potato is the only plant the Colorado beetle can feed on.	☐ True / ☐ False
3	The Colorado beetle was able to spread over a large area because people started to plant potatoes.	☐ True / ☐ False

The purpose of the item was to measure skills of students associated with analysing a short text and drawing conclusions from the presented information. No specific knowledge in biology was required. Quite surprisingly, many of the students seemed to ignore the key message carried by the text. For example, the fact that the most of its history the Colorado beetle had had no contact with the potato and the two organisms had only met relatively recently with human manipulation. Before that, given the absence of potatoes in the beetle’s natural environment, the insect, of course, was not able to feed on them (statement 2) or to regulate their population (statement 1).

Table 5. *The student (n = 1934) responses to the item The Beetle and The Potato. All three statements were judged correctly by 24.1% of the students.*

	True	False	No answer
Statement 1	38.8%	**59.9%**	1.3%
Statement 2	52.7%	**45.9%**	1.3%
Statement 3	**80.9%**	17.9%	1.3%

* The correct answers marked in bold.

The results presented in Table 5 show, however, that the majority of the students believed the potato was the only plant that Colorado potato beetle could feed on. It can be hypothesized as that this is mainly due to a very strong association between the beetle and the plant in the students’ minds. For decades in Polish schools, the Colorado beetle was one of the textbook examples of a crop pest and the food chain consisting of a potato plant, a Colorado beetle and a pheasant has been one of the first ones that a primary school student would encounter.

This association also has its vernacular component as the Colorado beetle's name in Polish is *stonka ziemniaczana*, the latter word being an adjective meaning "potato-related". This is, of course, not an exception, as reference to the host plant also appears in this name of beetle in English and many other languages. In French potato is called *pomme de terre* (literally "ground apple"), hence the name of the insect *doryphore de la pomme de terre*. In the Spanish name is *escarabajo de la patata* or *dorífora*, and the Italian one is *dorifora della patata*, there can be found the word *patata* meaning "potato" in both languages. The beetle's names in German is *Kartoffelkäfer*, and in Arabic خنفساء بطاطس كولورادو '*khunfusa' btats kuluradu'* also include words for "potato" (*Kartoffel* and *btats*, respectively), while in Russian the term is колорадский картофельный жук '*koloradskiy kartofel'nyi zhuk'* and in Czech *mandelinka bramborová*, there can be found adjectives *kartofel'nyi* and *bramborová* both mean "associated with potato". There seem to be relatively few languages in which the insect is simply called "Colorado beetle" without any reference to potato, i.e. *coloradoskalbagge* in Swedish or *kolorado hamushi* (コロラドハムシ) in Japanese.

But how does the association that reflects in a fact (after all, Colorado beetles do feed on potatoes) become a misconception? It is believed that the problem arises when an automatic association replaces thinking in a student's mind. To solve the problem, the students were not expected to know the history of the Colorado beetle. They were only asked to analyse a short text about it. Those, who did so, had a good chance to choose the correct answer. Nonetheless, if a student believed that the association was so obvious that there was no need to pay too much attention to the text, the misconception could take over.

This hypothetical scheme is not limited to vernacular misconceptions. An oversimplified view of a phenomenon lies at the heart of many other types of misconceptions. The fact that, following a simple association is much easier than analysing the problem critically makes them even more appealing not only to students.

Figure 2 shows the percentage of students who correctly judged the statement 2 as false in eight groups identified as described in method section of the manuscript (1 – the students with the lowest score in the test, 8 – the students with the highest score). Even though a completely random choice would have resulted in a 50% success rate, the correct answer prevailed only in group 8. Moreover, the curve in Figure 2 has the shape that was observed in several other items which diagnosed some types of misconception. The students from groups 1 and 2 generally represent the lowest level of competencies and/or the lowest motivation to solve the item. Their answers tend to be random and one can see that in this case the percentage of correct answers is close to 50% indeed. In groups 3 and 4, which did better in the test, there is, paradoxically, a significant drop in the number of correct answers. This is where the misconception manifests itself most vividly. These students tried to solve the item, but they probably failed due to the misconception. As the level of skills and knowledge grew (groups 5–8), the number of correct answers rose, but only the best students (group 8) had a success rate larger than 50%.

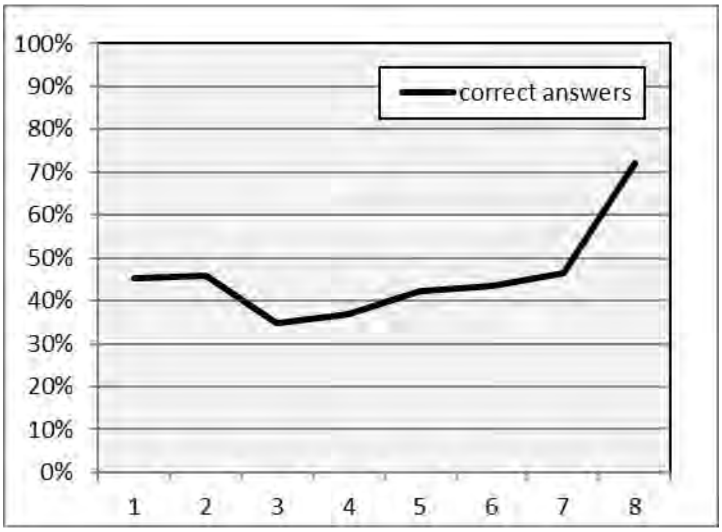
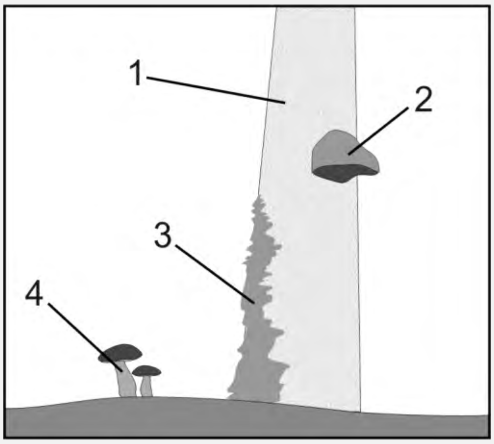


Figure 2. *The distribution of frequency of the students' answers to the second row in the question in The Beetle and The Potato item*

c) A term that only seems to be self-explanatory

The following item, *Birch, Moss and Fungi*, was presented to a sample of 251 ninth-graders (see Table 1) randomly chosen from 23 classes of lower secondary schools during the field trial but eventually was not used in the main study of the *Laboratory of Thinking*. The item is shown below as it was presented to the students during the field trial.

The picture shows four organisms living in a forest. Their names are listed in the table below.



For each organism, answer if it is an autotroph or a heterotroph.

	Organism	Heterotroph or autotroph?
1.	Birch	☐ Heterotroph / ☐ Autotroph
2.	Tinder fungus	☐ Heterotroph / ☐ Autotroph
3.	Moss	☐ Heterotroph / ☐ Autotroph
4.	Scaber stalk (a fungus)	☐ Heterotroph / ☐ Autotroph

The frequencies of the student responses are shown in Table 6.

Table 6. *The students' (n = 251) responses to the item Birch, Moss and Fungi. All the statements were judged correctly by 20.7% of the students.*

		Heterotroph	Autotroph	No answer
1.	Birch	19.5%	**80.1%**	0.4%
2.	Tinder fungus	**81.7%**	17.5%	0.8%
3.	Moss	57.8%	**41.8%**	0.4%
4.	Scaber stalk (a fungus)	**38.6%**	60.1%	0.4%

* The correct answers shown in bold.

The results show that most of the students either did not properly understand the meaning of the terms autotroph and heterotroph or could not apply them to plants and fungi. Moreover, one should note a significant difference in the percentage of correct answers between the first two and the last two organisms listed in Table 6 (~80% and ~40%, respectively). It is argued that such results may be due to the specific vocabulary used in Polish to describe autotrophy and heterotrophy.

In most languages the terms for autotroph and heterotroph are variations of Greek words αὐτότροφος '*autotrophos'* (from *autos* = "self" and *trophe* = "nutrition") and ἑτερότροφος '*heterotrophos'* (from *heteros* = "other" and *trophe*). To name a few examples: the French autotrophe, German Autotroph, Spanish *autótrofo*, Italian *autotrofe*, Czech *autotrofní organismus* or Russian автотроф '*avtotrof'*. In Polish the related words *autotrof* and *heterotrof* also exist, but the term *organizm samożywny* which means literally "self-feeding organism", and *organizm cudzożywny* ("organism feeding on others") is much more widely used especially in primary and lower secondary education. Among the examined languages in the study, a similar situation was found only in Japanese. An autotroph is called 独立栄養生物 '*dokuritsu eiyou seibutsu'*, literally "organism feeding independently" while a heterotroph is known as '従属栄養生物 '*juuzoku eiyou seibutsu'* – "organism feeding dependently". Therefore, both the Polish and the Japanese expressions have a similar meaning to the widely used terms derived from Greek. However there is an obvious difference in perception between words composed of stems and affixes coming from the mother language of the students and words derived from an unknown language (indeed, any Polish students are taught Greek in K12 nowadays).

To investigate the student understandings (or misunderstandings) for the terms of autotroph and heterotroph, the interviews were performed as described in the method section of the study. Most of the twelve interviewed students turned out not to know what autotroph and heterotroph meant, even though both terms are listed in the Polish national core curriculum. These interviewees also did not associate autotrophy with photosynthesis (at least not until guided by the interviewer). Therefore, many of the students tried to deduce the meaning of each term by analysing it. This led them to a false conclusion that an autotroph (in Polish "self-feeding organism") is an organism that "gains its food by itself", while a heterotroph ("organism feeding on others") is an organism that "feeds on someone else's expense" which makes it somewhat similar (or even equal) to a parasite.

The results from the interviews may explain why so many students classified the moss shown in the illustration as a heterotroph in the field trial. Probably the fact that, it was attached to another organism (birch) misled the students into thinking that it was a parasite like the tinder fungus. On the other hand, the saprophytic scaber stalk was incorrectly classified by most of the students as an autotroph, probably because it was depicted as growing from the soil, not from another organism.

In conclusion, an interesting vernacular misconception is associated with the Polish terms for autotroph and heterotroph. It is probably caused by the fact that these terms seem to be self-explanatory while their literal interpretation may be misleading indeed.

d) A term that usually appears in a misleading context

The item *Gas Boiler* shown in below was part of the first and the second cycle of the study *Laboratory of Thinking*.

There is a sticker on the gas boiler that reads:

In case you smell gas:

✓ Shut the gas valve
✓ Open the windows
✓ Avoid switching on electrical devices
✓ Extinguish all naked flame
✓ Call the gas emergency service and the gas installation service
Source: gas boiler manual

Which of the gases does the instruction on the sticker concern?

A. Carbon dioxide.
B. Carbon monoxide.
C. Natural gas.
D. Oxygen.

The responses of students to the item *Gas Boiler* are listed in Table 7. In the first cycle, the number of students was 1953 and in the second one it was 1874.

Table 7. *The students' (n1 = 1953; n2 = 1874) responses to the item Gas Boiler*

Answers	Students' choices	
	1st cycle	2nd cycle
A. Carbon dioxide.	13.3%	13.3 %
B. Carbon monoxide.	32 %	33.8 %
C. Natural gas.	**52 %**	**50.5 %**
D. Oxygen.	1.8 %	1.7 %
More than one answer	0.3 %	0.3 %
No answer	0.7 %	0.4 %

* The correct answers marked in bold.

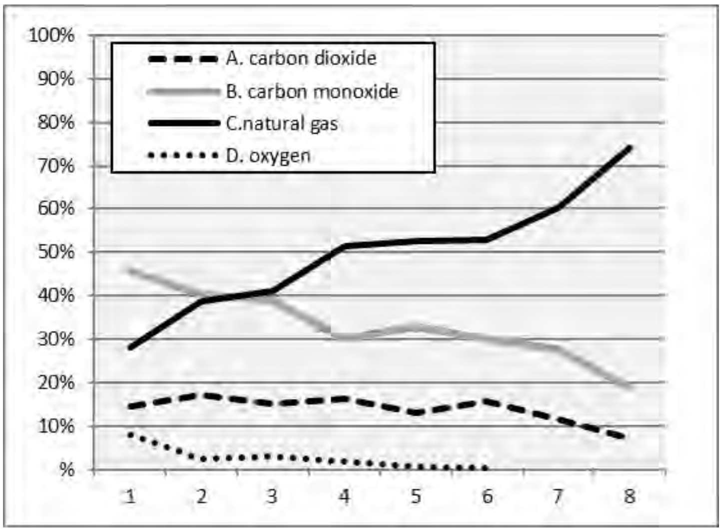


Figure 3. *The distribution of frequency of the student answers to the question in the Gas Boiler item*

The chart (Figure 3) shows the students' answers to the question. On the X axis the level of students is marked (1 being the group of the students who scored worst throughout the test, and 8 being the best scoring group), and the percentage of students from both groups who chose a given answer shown on the Y axis. The chart shows the results for the first cycle (in the second cycle, they were analogous).

The level of students' skills was higher when the percentage of correct answers was higher (i.e. "C. Natural gas."). The percentage of incorrect answers decreases along with the octile number. Yet, it should be noted that the answer B ("Carbon monoxide") clearly stands out. The percentage of B answers oscillates between 45.8% in students from the first octile and 18.8% in students from the last octile in the first cycle and 43.8% and 23.3% in the second cycle respectively.

It can be seen that students scored similarly in both cycles. The correct answers significantly outnumber the incorrect ones, beginning with the fourth octile (first cycle). Therefore, the task distinguishes average students from both good and poor students.

The first learning outcome in the Polish core curriculum for teaching chemistry at ISCED2 level is critical analysis of information: the student acquires and processes data from different sources through using information and communication technology. The context of the presented item is set in an everyday situation. The information provided in the stem comes from an actual sticker on a gas boiler. It is obvious that a grown-up citizen should be able to use data from the stem and draw conclusions from them. From a public health perspective, Omaye says that CO poisoning may be the cause of more than 50% of fatal poisonings in many industrial countries (Omaye, 2002).

Students should be familiar with the properties of all gases that appear in the item given the fact that they are listed in the curriculum and are recommended for experiments to be conducted in class (obtaining oxygen, hydrogen, carbon dioxide, examining their properties, detecting carbon dioxide in exhaled air).

A set of interviews was performed to learn more about the reason behind the student answers and the following conclusions were drawn based on them. When the students were asked why such information appears on gas boilers, it was obvious to them that it was for safety reasons. All but one of them managed to analyse the content of the instruction and knew the meaning of all of its subsections. It turned out that no more than a quarter of the students made a fully conscious choice. Some of the students knew the properties of the gases, but anyway they selected "carbon dioxide". Only a third of the interviewees knew that carbon monoxide was toxic and most of the students associated it with fires. Only one person knew the reason that natural gas had to be odorized and understood the term "odorization". The students' knowledge was fragmentary about O_2, CO_2, CO and CH_4 and their properties in standard conditions for temperature and pressure. Some of them were able to say (when guided) that carbon monoxide was toxic, while the others knew the properties of oxygen (e.g. that it is necessary for breathing). Only one person knew the formula for CO_2 and a quarter of the students knew what gas is used in cookers.

There are two main problems that ought to be stressed. First, students do not know the properties of methane (being combustible, odourless, colourless etc.). Second, most of the students associate carbon monoxide with smoke and fire. This may result from the image that is found in the media: people usually hear of carbon monoxide on the news when there is a fire emergency, therefore they mistake carbon monoxide for fire smoke (grey or black clouds, irritation of the eyes and throat, unpleasant smell of burning matter). Data of exemplary verbal probing interviews are gathered in Appendix 3 (transcribed verbatim).

This may be perceived as a vernacular misconception since the common name of carbon dioxide in some languages may be misleading. For example, (*kolendamp*) in Dutch, (*kolshacha wayu*) in Hindi or (*fumée de carbone*) in French literally means "vapour of coal", "gas of coal" and "smoke of coal", respectively. In Spanish, it is sometimes referred to *gas carbonoso* ("coal gas"). Thus, all of them refer to the idea of burning fuel and other materials that produces clouds (visible and odorous). In Polish – the language our study was conducted in – it also seems deceptive, since the Polish word *czad* appears to be related to *kadzić* ("to incense"), albeit mistakenly, and makes many people immediately think of dense, acrid smoke. Some Poles also colloquially use the word *czadzić* to mean "to reek" or "to break wind" which explains why many people are sure *czad* ("carbon monoxide") must have a smell.

DISCUSSION and CONCLUSION

There is not one language that could meet all the communication needs of individual or communities. Many languages, sublanguages, terminologies and registers coexist and intermingle as different domains of life come close to one another and overlap. Denotation is strictly connected with connotation and context, thus the awareness of their existence and relationships between them is a crucial factor in understanding the communication process and makes it possible to choose appropriate strategies. Teachers and students tend to speak different, separate languages, and often they are not conscious of that fact. This obviously leads to dissatisfaction of both teachers displeased with the learner results and the learners discontented with the teacher hermeticism. Although this dissatisfaction may seem frustrating, it also opens way to reaching a strategy that is means fruitful, plausible and intelligible (Posner, 1982), a strategy that works. Such a strategy is the way to undergo a conceptual change that helps to overcome the cognitive conflict and acquire a new language that opens new cognitive perspectives. There are three main types of conceptual change: firstly, *simple accretion*, that is adding new information (Chi, Slotte and Leeuw, 1994); secondly, *weak knowledge restructuring*, also referred as *assimilation* (Posner, Strike, Hewson and Gertzog, 1982) or *conceptual capture* (Hewson, 1981, 1982, 1985, 1992, 1996); and thirdly, *strong restructuring* (Carey, 1985, 1986, 1991), *radical restructuring* (Vosniadou, 1994), *accommodation* (Posner, Strike, Hewson and Gertzog, 1982) or *conceptual exchange* (Hewson, 1992) which means the old conception being replaced by the preceding one (or the previous one being sustained and the new one discarded).

The conceptual change may be related to *knowledge-as-theory* perspective (Ioannides and Vosniadou, 2002) or *knowledge-as-elements* perspective (diSessa, 1988), the former referring to simple *phenomenological primitives* (*p-prims*), and the latter using the notion of *misconceptions*. Phenomenological primitives can be considered as simple abstractions which generally need no verbal explanation (diSessa 1988), such as intuitively understandable principles: "the stronger the agency, the stronger the effect; the stronger the impediment, the weaker the effect". Language *per se*, even in its simplest manifestations, is a more complex medium which inherently presupposes more indirectness (objects and ideas are not experienced as such, proximally, but distally, through the medium of phonology, lexis, syntax etc.), therefore terminology involved conceptual change requires a specific type of analysis that considers the phenomena on linguistic level. Such an approach requires a deeper differentiation of diverse kinds of misconceptions that arise when different terminological systems meet: mainly when formalized scientific discourses is confronted with every-day, common speech.

The presented paper was aimed at naming different types and sources of vernacular misconceptions identified with the use of our long-term *Laboratory of Thinking* study. Four types of misconceptions were distinguished related to language found in students. These may be called:

- *amphibological misconceptions* (when a term has one meaning in science and another one in everyday life), as in *A Cloud Over the Cup*,
- *hypernimical-hyponimical misconceptions* (when a term suggests a stronger or narrower denotation than it has), as in *The Beetle and The Potato*,
- *pseudodeictic misconceptions* (when a term appears to be self-explanatory while it is not), as in *Birch, Moss and Fungi*, and
- *contextual misconceptions* (when a term usually appears in a context that gives a wrong impression about its actual meaning), as in *Gas Boiler*.

Each of the types was illustrated and discussed based on an example of an educational diagnostic tool through both quantitative and qualitative analysis. Sometimes it is difficult to make a clear distinction between the purely linguistic, terminology-related misconception and what is beyond words in it, that is the factual content and the extralinguistic context.

The relative scarceness of sources concerning specifically vernacular misconceptions may be because this issue is somehow neglected as a very narrow problem connected to the language of a given country or that may be easily corrected (Committee on Undergraduate Science Education, 1997), whereas it may actually be a universal and common hindrance that impedes student learning throughout the world. Unlike Bloom (1956), it is thought that this sort of problem is not a lower-level issue, because what seems easy and basic to some, may require higher cognitive level and more effort from others. Once again it should be stressed, according to Mason (2006), that memorizing simple words, as we often do, e.g. when learning a foreign language, is not the same as learning and understanding scientific terms and facts that underlie their definitions. Furthermore, as Gütl and García (2005) stressed that difficulty of conteptual learning must not be underestimated since not all scientific concepts are concrete and simpler to learn, also there are complex and abstract concepts, ,. What is more, it may be seen from the present study that many people do not really understand many fundamental concepts of science and as Nakhleh (1992) states that sometimes they may never be able to make up for it even as university graduates and postgraduate students.

Students tend to perceive the language used in class and the terminology connected with it as an abstract dialect (somehow similar to a dead language), that is only used for teaching and learning and has nothing or little to do with the so-called ‘real life’. Therefore, students may often not question the words of teacher, because they are used to hear things at school that are unclear, unfamiliar, and obscure. So, if they hear another unclear statement or term, they may not react to it. Consequently, it often happens that a teacher explains the subject matter to students who later give seemingly correct answers to his or her questions, but both parties are unaware of the fact that, in fact, they mean different things.

As described above, the terms *organizm samożywny* (“autotroph”) and *organizm cudzożywny* (“heterotroph”) were misinterpreted by students. It should be emphasized that the primary problem was that the students did not know what *organizm samożywny* (“autotroph”) and *organizm cudzożywny* (“heterotroph”) meant, and this was what made them try to figure out the meaning of these terms based on how they sounded. Instead, the words *autotrof* and *heterotrof* had been used, probably the only difference would have been the lack of any guesses at all. Of course, such a change from a "wrong idea" to "no idea" is not our goal. It is believed that the term "producer" (Polish *producent* widely used in the literature) mean "an organism that produces its own food" describes an autotroph much more accurately than the expression "self-feeding organism".

Another discussed problem – that of the Colorado potato beetle – is different as the association between the plant and the pest is generally correct and the students' only mistake is to perceive it as an exclusive and obligatory one. It is not the only example in which the name itself is misleading. There are even worse, such as *horseshoe crab* (having nothing to do with horses, shoes or crabs) and *jellyfish* (being neither jelly nor a fish), or even more misleading because it is partially true such as *earthworm* (which does have something to do with soil but is not a worm).

The problem of misconceptions related to carbon monoxide has been examined by many authors (Derek, Velázquez-Angulo and Witherspoon, 2006; Penney, 2007; Pérez, Galada *et al*., 2009). However, linguistic issues did not focus that may be the reason for these misconceptions. As it is stated afore, this misconception may be rooted in the language itself, and a reason for student mistakes may be the use of common (trivial) names.

There are numerous analyses concerning the problem of perceiving steam/water vapour concepts by students (Osborne and Freyberg, 1983; Stavy, 1990; Bar and Travis, 1991; Canpolat, Pinarbasi and Sözbilir, 2006; Håland, 2009 and González, 2010) and the problem seems to be related to concrete thinking of students that appear not to be able to internalize a phenomenon which is invisible. It is much easier to replace the hardly imaginable picture of invisible and odourless water vapour with visible clouds of condensed water droplets. When a phenomenon seems somehow exotic or mysterious to the students, it stands out and it is easier to notice and remember its properties, whereas the things that seem common and ordinary may pass unnoticed both by students and by teachers. Steam or vapour are everyday speech words that may seem deceptively familiar, whereas in the scientific context they may not be so.

Fighting misconceptions is difficult and often ineffective. It seems to be possible only if it is recognized and acknowledged about them (Sadler and Sonnert, 2016). As described by Tippet, a universal method is therefore to directly address the misconception in a so-called refutation text (Tippet, 2010). Dated 1984–2011, other more or less useful methods, have been summarized by Yang and Senocak (2013) is using conceptual conflict to confront and contradict student misconceptions and inducing students to reflect on their conceptions through computer simulations to facilitate conceptual change and correct misconceptions, inquiry-based approach, presenting conditions of the Conceptual Change Model (CCM), using schema training approach to train students on two scientific processes (domain-general). However, none of them is targeted specifically at fighting vernacular misconceptions.

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Appendix 1

List of general and item-specific questions asked to the students during interviews

General questions	Item-specific questions	
	Item	Question
- Did you understand the question stem? - Did you understand the instruction? - Did you find the graphics clear? - Why did you choose such answers?	A cloud over the cup	- What were you thinking when you chose the answer in task 1? Have a look at your answer in the second part of task 2. Do they match each other? - What do you think the reason for the laundry dries up? - What weather phenomenon does the cloud over the cup remind you of? - What is fog? How is it created? - What happens if you breathe out air on a freezing day? - At what temperature does water boil and evaporate? Does it always boil at 100 °C? Does pressure affect the boiling of water?
	Birch, Moss and Fungi	- Do you know what the difference between autotrophs and heterotrophs is? If the student answered "autotroph is an organism that feeds on its own": - Am I [i.e. the interviewer] an autotroph? - Are the notions of autotroph and heterotroph related to whether the organism carries out photosynthesis or not?
	Gas Boiler	- Why is there an instruction sticker on the boiler? - What is the purpose of each information on the sticker? - What are the properties of carbon dioxide? - What are the properties of carbon monoxide? - Under what circumstances is carbon monoxide created? - What sort of gas is present in gas cookers? What does it smell like? - Do you know what gas odorization is? - What are the properties of oxygen?

Appendix 2

Exemplary student statements from the interviews when justifying their choice of answer in the item: *A Cloud Over the Cup*. The statements are transcribed verbatim.

- When there's hot water, there's a visible cloud, that is vapour.
- The cloud over the cup of coffee is hot air, which after meeting cold air becomes visible because the water condensates.
- If in the cup there is boiling water, the water evaporates. It changes from liquid to a visible gas.
- Because it looks like smoke.
- I've seen a cup many times and there was smoke above it.
- If there's something warm, droplets of water rise above it and form a cloud.
- Warm tea or coffee steams with a dim smoke.
- Why the smoke steams.
- I guess whenever tea boils there's smoke.
- The tea is hot, and that's why there is smoke.
- I think so because the cloud is in the sky, and vapour can appear over the cup.
- Vapour is, kind of, some white smoke.
- I've seen such smoke many times.
- Vapour is hot smoke that means the thing is hot.
- It is a colourless cloud.
- Hot water evaporates, which causes a white cloud to appear.
- Water after heating starts to evaporate, which appears as a white cloud.

Appendix 3

Exemplary student statements from the interviews when justifying their choice of answer in the item: *Gas Boiler*. The statements are transcribed verbatim.

- Carbon monoxide is when there’s a fire.
- When there’s a fire, we can smell that smoke.
- This carbon monoxide leaves dark stain.
- When there’s a fire, people die because of this smoke (when it’s about carbon monoxide).
- Carbon monoxide is grey and toxic. On TV they showed a fire and people were poisoned.
- Carbon monoxide makes you choke.
- Clouds of smoke.
- On the news they said that people got poisoned with carbon monoxide. They showed fire and smoke.