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Laboratory jargon and misconceptions in Chemistry – an empirical study

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ABSTRACT

Lecturers mostly use "laboratory jargon" in their seminars and the question comes up whether teacher students are taking this jargon for their terminology, developing "school-made misconceptions", or even transferring them later into Chemistry instruction. One example: "2 hydrogens react with 1 oxygen to form 2 water" is often heard – instead of pointing out that 2 H_2 molecules and 1 O_2 molecule are forming 2 H_2O molecules. This last statement is totally clear and the learner will develop applicable mental models. An empirical pilot study shows the first results. About half of the investigated participants could reflect on and correct given jargon statements – but even after three years of studying Chemistry, the other students are staying with that jargon or other alternative conceptions.

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1. INTRODUCTION

Chemistry experts at universities may use an incorrect terminology called "laboratory jargon". The expert wants to change information by short statements, and he or she can be sure that the colleague will understand what it *means*. But learners will be irritated and not know what is *meant*. For example, the Broensted theory is introduced nearly in all lectures. The jargon reaches also the acid-base topic: "Water can be an acid or base" is a well-known jargon (Barke & Büchter, 2018), and the expert knows that the H_2O molecule is *meant*. The learner knows pure water with a melting point of 0°C, a boiling point of 100°C, a density of 1 g/mL, or a pH of 7. The question is rising whether he or she should believe that pure water may change to the pH of 5 or pH of 10 or not. If lecturers would take the correct term according to the Broensted theory (Barke & Harsch, 2014), this statement would be correct: "The H_2O molecule can react as an acid particle or as a proton donor (donor of H^+ ions)", with another partner, it may react as a base particle or a proton acceptor.

(i) H_2O molecule as a *donor*: H_2O molecule + NH_3 molecule → NH_4^+ ion + OH^- ion

(ii) H_2O molecule as an *acceptor*: H_2O molecule + HCl molecule → H_3O^+ ion + Cl^- ion

Here, the purpose of this study was to do an empirical study about "Laboratory jargon and misconceptions in Chemistry".

2. METHOD

This study was to understand and to know how chemistry-teacher students are influenced by the laboratory jargon concerning Broensted's acid-base theory which requires molecules or ions as proton donors or acceptors – and not substances. Otherwise, students may even develop misconceptions (Barke *et al*., 2009). In our hypothesis, students after studying three years of Chemistry at Muenster University in Germany are mostly not able to reflect or correct statements on the base of the jargon (Barke & Büchter, 2018).

2.1. Questionnaire

We constructed 10 multiple-choice problems with a jargon statement at the beginning and the task to mark from four possible alternatives the correct terminology on basis of Broensted's theory. Detailed questions are

(i) Laboratory Jargon: "Carbon dioxide consists of carbon and oxygen"

a) CO_2 consists of one C and two O.
b) Carbon dioxide consists of carbon and oxygen.
c) CO_2 consists of one carbon part and two oxygen parts.
d) The carbon dioxide molecule CO_2 consists of one C atom and two O atoms.

(ii) Lab. Jargon: "Hydrochloric acid gives off a proton"

a) Hydrochloric acid can be deprotonated.
b) Hydrochloric acid can also absorb protons.
c) $H_3O^+(aq)$ ions are present in hydrochloric acid, they can emit protons.
d) HCl molecules are present in hydrochloric acid, they release protons.

(iii) Lab. Jargon: "Water dissociates, shows equilibrium of H^+ and OH^- ions"

a) The equilibrium of the water yields protons and hydroxide ions.
b) Water can split off both H^+ ion and OH^- ion.
c) Autoprotolysis of H_2O molecules yields H_3O^+ ions and OH^- ions.
d) Water provides protons and hydroxide ions in autoprotolysis.

(iv) Lab. Jargon: "Ammonia is a weak base"

a) NH_3 molecules are weak bases, they are in equilibrium with corresponding ions.

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b) Ammonia solution is weakly concentrated.
c) NH_3 molecules react completely to NH_4^+ ions.
d) Ammonia forms ammonium chloride, NH_4Cl.

(v) Lab. Jargon: "The concentration of water is c = 55.5 mol /L"

a) The concentration of H_2O is 55.5 mol / L.
b) The concentration is c = 55.5 mol H_2O molecules per liter.
c) Water consists of 2 mol of hydrogen and 1 mol of oxygen.
d) Water consists of 100% hydrogen and oxygen.

(vi) Lab. Jargon: "Sodium hydroxide dissociates by water into Na^+ ions and OH^- ions"

a) NaOH molecules dissociate by water into Na^+ ions and OH^- ions.
b) Solid NaOH consists of Na^+ and OH^- ions, in water they form $Na^+(aq)$ and $OH^-(aq)$ ions.
c) Na^+OH^- ion pairs of solid sodium hydroxide are separating into single ions.
d) In water the Na atoms and OH groups transfer electrons to form Na^+ ions and OH^- ions.

(vii) Lab. Jargon: "Hydrochloric acid neutralizes sodium hydroxide to water and salt"

a) Neutralization means salt formation.
b) After neutralization, equal concentrations of acid and base are present.
c) $H^+Cl^-(aq) + Na^+OH^-(aq) \rightarrow H_2O + Na^+ Cl^-(aq)$.
d) $H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \rightarrow H_2O + Na^+(aq) + Cl^-(aq)$.

(viii) Lab. Jargon: "Strong acids have a low pH, weak acids a higher pH"

a) Strong/weak acids are strongly / weakly concentrated.
b) The pH value indicates the concentration of the acid.
c) The pH value indicates the concentration of H^+ ions.
d) Weak acids have a pH between 3 and 6.

(ix) Lab. Jargon: "Indicator papers indicate the strength of an acid"

a) Indicator papers indicate how strong an acid is.
b) Indicator papers show strong or weak acids.
c) Indicator papers indicate how concentrated acid is.
d) Indicator papers can indicate whether acid or base is present.

(x) Lab. Jargon: "Water is an ampholyte, it can be acid and base"

a) The H_2O molecule is an ampholyte, it can accept a proton, and can give a proton.
b) Water can be both acid and base.
c) H_2O is acid and base simultaneously, molecules dissociate to H^+ and OH^- ions.
d) Water can be acidic, basic, or neutral.

2.2. Realization

In Germany, we have chosen a group of about 50 chemistry-teacher students who are studying at the end of their 6th semester. They studied Inorganic, Organic, and Physical Chemistry to be a high-school teacher in their future. During one hour in a special seminar in June 2017, they solved the tasks of the questionnaire.

3. RESULTS AND DISCUSSION

Following our hypothesis for the pilot study according to laboratory jargon and misconceptions of students, we used the questionnaire with well-known jargon statements. We want to know how those statements will be reflected successfully and if correct answers will be found. Otherwise, students may stay on the jargon and develop misconceptions – and would even take those misconceptions as future chemistry teachers into their lessons.

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Students got the 10 multiple-choice problems with a jargon statement at the beginning and the task to mark from four possible alternatives the correct terminology on basis of Broensted's theory. One example of the questionnaire (Barke & Büchter, 2018):

(ii) Lab. Jargon: "Hydrochloric acid gives off a proton"

a) Hydrochloric acid can be deprotonated.

b) Hydrochloric acid can also absorb photons.

c) $H_3O^+(aq)$ ions are present in hydrochloric acid, they can emit protons.

d) HCl molecules are present in hydrochloric acid, they release photons.

The right answer is (c): "$H_3O^+(aq)$ ions are present in hydrochloric acid, they can emit protons": 40% of participants chose it. We took the famous misconception (d) and we are waiting for "HCl molecules": only 5% have marked it. Because of the well-known idea of "deprotonation", we offered an alternative (a) – and 55% were thinking of the scientifically good sound of "deprotonation".

Dr. Yuli Rahmawati from Universitas Negeri Jakarta took the same questionnaire and tested Indonesian university students (Barke & Ramawati, 2019). She found that only 15% of her students marked the correct alternative. She took also the German results and compared them with her right answers (see **Figure 1**).

Task 2: „Laboratory Jargon: Hydrochloric acid gives off a proton. Which is the scientific right sentence?"

a) Hydrochloric acid can be depronoted.

b) Hyd. acid can also absorb protons

c) $H_3O^+(aq)$ ions are present in hyd. acid, they can emit protons.

d) HCl molecules are present in hyd. acid, they release protons.

Only 15 % of Indonesian students chose the right answer c – they mostly wanted answer d, thinking of „HCl molecules".

Questions	German	Indonesia	
1	68	92	84
2	40	15	19
3	90	54	50
4	77	63	59
5	55	48	45
6	22	25	33
7	50	15	22
8	82	83	65
9	64	70	87
10	55	23	31
	Year 3	Year 3	Year 1-4

Figure 1. Indonesian and German correct answers (Barke & Rahmawati, 2019).

Nearly in every task more than 50% of **German students** marked the right answer – they can successfully reflect statements in the jargon and are thinking in scientific ways of the acid-base terminology. In detail, there are the following differences.

(i) In **Task 1,** we offered the common statement "Carbon dioxide consists of carbon and oxygen". Statements (a) and (c) are a mix of substances and particles, and (b) point out that carbon dioxide is composed of carbon and oxygen – crystals of carbon and bubbles of oxygen? The only correct answer should be "(d) the CO_2 molecule consists of one C atom and two O atoms". 68% of students took it, and each other answer reached about 10% of the markings.

(ii) For **Task 2,** see the example at the beginning of this chapter.

(iii) In **Task 3,** we offered "water dissociation". Indeed, the autoprotolysis of H_2O molecules is meant – so answer (c) is the right answer, chosen by 90% of students. In this case, nearly all students reflected the jargon statement in the right way. Only a few answers were going to the other alternatives.

(iv) In **Task 4,** we offered "Ammonia is a weak base". Also in this case most students (77%) argued in Broensted's way: "(a) NH_3 molecules are weak bases". Other answers were taken by only a few students.

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(v) In **Task 5,** we offered the famous statement "the concentration of water equals 55.5 mol/liter". The mole idea deals with high numbers of particles (Indriyanti & Barke, 2014) and only with those special numbers of particles it makes sense to state: "(b) the concentration equals 55.5 mol H_2O molecules/liter". This answer was given by only 55%. The other students (45%) might have thought about masses in the way that "1 mol water means 18 g water" – and 1000 g of water contains 55.5 times 18 g. Answers (c) and (d) were not chosen.

(vi) In **Task 6,** "dissociation of sodium hydroxide" as jargon statement is offered. We were waiting for students, which are not thinking of ions in solid sodium hydroxide, which may think scientifically wrong of "NaOH molecules" or "Na^+OH^- ion pairs". 62% of students took "a) NaOH molecules", 13% the answer "c) Na^+OH^- ion pairs". Only 22% of students gave the right answer (b), and (d) was chosen by 3%.

(vii) In **Task 7,** we offered the neutralization "by substances to salt and water" and wanted the description according to Broensted's theory (d). This answer was marked by 50% of students. The other half of the students were thinking of "(c) ion groups" (30%), of "salt formation" (15%), and 5% of "equal concentrations of acid and base".

(viii) In **Task 8** we offered "strong and weak acids and their pH". The right answer is "(c) pH values indicate concentrations of H^+ ions", and 82% of participants decided right. There were 9% markings of (b) and (d), and "(a) salt formation" was not chosen: a good result.

(ix) In **Task 9,** we offered "indicator papers indicate the strength of an acid". The easiest right answer is (d). 64% took this choice. The other students marked the three other alternatives with low percentages.

(x) In **Task 10**, we offered the misunderstanding that "water can be acid and base". As discussed before the H_2O molecule can only be called an ampholyte – nicely 55% of students marked (a). But, the statement "(b) water can be acid and base" was chosen by many students, about 35% took the laboratory jargon without reflecting on this statement. About 10% decided "(c) H_2O is acid and base simultaneously". We wish to do interviews with those students to know what mental model they have in their minds.

Students answered in the majority well. More than half of the participants reflected the jargon statement in the right way and chose the right alternative. They can apply Broensted's theory successfully, they are thinking on the Sub-micro level (Johnstone, 2000) (**Figure 2**) and have developed applicable mental models about the structure of matter. So we must reject our hypothesis: The majority of German students are capable to reflect and to correct statements in the laboratory jargon on sub-micro level (see **Figure 2**).

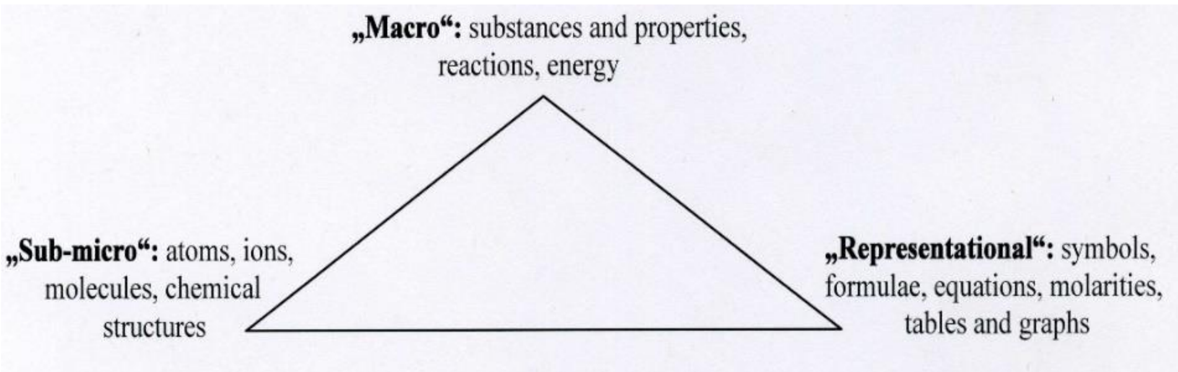

Figure 2. Johnstone's idea of a chemical triangle (Johnstone, 2000).

The other students are showing a lack in this aspect. Either they mix substances and particles in a not acceptable way or they are thinking only of substances like "water can be an

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acid or base" or "concentration of water is 55.5 mol/L". Those students have developed wrong conceptions from laboratory jargon – or they are working mostly on the macro-level of substances and have not developed sufficient mental models to think on sub-micro level. They should learn to argue with substances consequently on the macro level and to interpret chemical reactions with atoms, ions, or molecules consequently on the sub-micro level.

4. CONCLUSION

This study was a pilot study. About 50 students were involved and we did no interviews with those students who answered in the wrong way. For new investigations, we should add for every question "give reasons" – students have to show reasons for their marked choice. We also have to review the questionnaire and should take away those alternatives, which are not marked by any participant – they make no sense for evaluation. We plan structured interviews to get more knowledge of kinds of misunderstandings or even misconceptions.

Also, the question of whether misconceptions are developed by laboratory jargon or by other teaching mistakes is not answered yet. The only way to get an answer is to watch lectures and observe, to which extent lecturers are using the laboratory jargon. For next studies the investigator has to look at lectures according to acids and bases and should construct the questionnaire according to used jargon statements. If students work with a special textbook the investigator has also to look at jargon expressions that may exist there. In every case, the lecturers in universities and teacher colleges should know about this problem and should avoid any laboratory jargon. Otherwise, teacher students will transfer jargon statements into schools, and even learners will develop misconceptions.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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