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Chemistry Content Knowledge of University Freshmen: A Relevant Aspect for the Desgn of Introductory Chemistry Courses

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Abstract

At universities in Germany many students drop out of their science study programs. Among many other reasons, students' lack of knowledge and failing of tests in the first terms are the most common ones to explain these dropout rates. A possibility to diminish these dropout rates is to establish introductory courses which take place before students' first term.

In order to establish an effective chemistry introductory course at the Georg-August-University Göttingen, we carried out interviews with the university teaching staff concerning their subject specific wishes and requirements to freshman students. Additionally, we conducted a study to determine the prior knowledge of chemistry students in major and minor programs at the beginning of their first term (n = 310). The aim of this study was to survey first term students' content-specific deficiencies in the fields of atomic structure, chemical bonding, chemical reactions, stoichiometry and basics in organic chemistry in order to adapt the content and the methods of the course with respect to the teachers' and students' demands.

The purpose of this contribution is to describe the basic chemical knowledge deficiencies of university freshmen at the Georg-August-University Göttingen by presenting the results of our study. Finally, we will discuss the impact of this study on the design of our introductory course.

1. Introduction

In Germany, the dropout rate in science programs, especially in chemistry, is above the average level of dropouts in other study programs. Two different studies from 2004 and 2008 show that the average dropout rate in science is 28 % whereas in chemistry it is 31 % [1]. There are many different reasons to explain the higher dropout rates in chemistry, but besides the high requirements of the study programs and the lack of students' chemistry content knowledge, their failing of tests is the most common one [2].

There are many possible influences on this lack of chemistry content knowledge in university freshmen. On the one hand, in most German schools the concept of scientific literacy constitutes science teaching. According to this concept, focus is placed on students' ability to recognize and explain scientific phenomena in their surroundings and in media related to socio-scientific issues rather than on deepening their knowledge of science concepts [3]. On the other hand, students' level of knowledge differs according to the type of chemistry class they attended in high school, *e.g.* whether or not they attended A level courses.

To ensure that all students depart from the same basic chemistry knowledge we want to establish an introductory chemistry course at the Georg-August-University Göttingen taking place before students' first term to reduce the dropout rate of our chemistry major and minor study programs. In order to describe the lack of knowledge that first term chemistry students have specifically, we conducted a study to determine the prior knowledge in chemistry students by developing a respective chemistry test. In this contribution, we will give an overview of the results of this study and we will discuss the relevance of these results for the design of learning modules in an introductory chemistry course.

2. Methods

The elicitation of the contents for the learning modules in our introductory course was carried out in interviews with the university teaching staff while considering the results of studies on introductory courses in chemistry and the contents of national school curricula [4,5]. Overall, the decision was made to develop learning units on the structure of matter, chemical bonding, chemical reactions, stoichiometry and an introduction to organic chemistry.
Furthermore, learning objectives with respect to the selected contents were formulated. To determine whether or not first term students have mastered these learning objectives, a chemistry test consisting of 48 tasks with definite response options was developed. The tasks cover all five topics mentioned above and each task concerns one certain learning objective. If possible, the response options for each task include typical misconceptions in chemistry as distractors [6]. All tasks refer to the cognitive steps of remembering, understanding and appliance [7]. The final test was taken by 310 freshmen from major and minor chemistry programs at the Georg-August-University Göttingen in november 2013. The following figures show three different example tasks from the test.

The ionic bond is characterised by…
☐a constant exchange of electrons between cations and anions.
☐the interactions of one or more pairs of electrons with two nuclei.
☐the interactions of at least two single occupied orbitals from two different atoms.
☐the electrostatic interactions of cations and anions.

Figure 1. Example test item regarding students' knowledge about the ionic bond.

In this task, students have to characterise the ionic bond. Thereby, an appropriate definition of the ionic bond has to be remembered. The first response option states a typical misconception and is therefore a distractor [6].

A sodium atom (shown in the picture on the right) forms a single positively charged cation. How would you explain this phenomenon using the atomic shell model?
☐It is a phenomenon, which cannot be explained using the atomic shell model.
☐If it donates one electron, it would have noble gas configuration and a full outer shell.
☐An electron at the innermost shell is donated very easily, because the atomic nucleus only contains 11 protons.

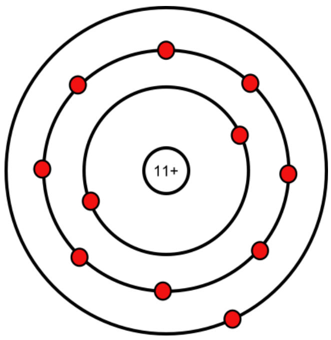

Figure 2. Example test item on the explanatory power of the atomic shell model for a sodium cation.

The task in figure 2 refers to the learning objective to explain the formation of an ion using the atomic shell model.

Draw the Lewis structures of the following molecules including non-binding pairs of electrons: N_2, CO_2, H_2S, CH_4, SO_4^{2-}.
For example: H_2 H—H

Figure 3. Example test item concerning the drawing of Lewis structures for different molecules.

In figure 3, the task refers to the learning objective of drawing Lewis structures for different molecules respecting the electronic configuration of the different atoms and the octet rule.

3. Results

Table 1 shows selected data from the test analysis. Each topic differs significantly from each other topic ($p < 0.001$). The *mean* is the average of the correctly answered questions, *sd* the standard deviation and *ratio* the quotient of the mean and the number of questions.

Topic	Mean	sd	Ratio
structure of matter	5.26	1.837	0.526
chemical bonding	2.77	2.004	0.277
chemical reactions	1.15	1.206	0.128
stoichiometry	3.15	1.545	0.450
organic chemistry	2.32	2.096	0.232

Table 1. Selected data from the analysis of the test.

In table 2, the ratio of the correct answers for the three example tasks describe above are displayed.

Example Task	Ratio of Correct Answers
Figure 1 (ionic bond)	0.384
Figure 2 (shell model)	0.913
Figure 3 (Lewis structure)	0.001

Table 2. Ratio of correct answers of the three example tasks mentioned above.

4. Conclusion

This study shows that the university freshmen tested by us have deficiencies in all five topics addressed in the test (Table 1). Particularly, tasks on the topics chemical bonding, chemical reaction and organic chemistry were answered with low results. Thus, the learning units for the introductory courses should place special emphasis on these. Table 2 shows that some tasks in the categories were answered correctly by a majority (Figure 2) while others were mostly answered incorrectly (Figure 3). In this respect, one can see that the results of our study also help to focus on certain learning objectives within the general topics. Students seem to have severe problems with drawing Lewis structures. One possible way to counteract this could be the implementation of cooperative learning sessions in which students help each other to draw Lewis structures for simple molecules.
Finally, the results demonstrate the lack of basic chemical knowledge in chemistry freshmen and emphasize the importance of the development of an introductory course in chemistry.

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