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The Chemical Formula Language: a Blended-Learning Course Design for the Transition between School and University

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Abstract
Results of recent studies concerning the subject specific knowledge of chemistry freshmen reveal several deficits in the area of the chemical formula language.[1] These include, for example, the formulation of simple molecular and structural formula, as well as their application in reaction equations and mechanisms. Furthermore, the description of basic chemical concepts on the representational level (symbolic formula),[2] e.g. concepts of acid-base and redox chemistry, turned out to be challenging for students at the beginning of their chemistry study. These deficits also became apparent in studies carried out frequently by us with freshmen of chemistry, including both students of chemistry in minor and major.[3]
Since mastery of the formula language is fundamental for the understanding of qualitative and particularly quantitative relations in chemistry and frequently being the first obstacle for the chemistry students, a preparatory course was developed at the faculty of chemistry of the university in Göttingen. That course intends to reduce or even to close knowledge gaps concerning the freshmen´s deficits occurring when the formula language is a prerequisite.
In our contribution we will initially present a categorisation of the chemical symbolic formula and based on this a didactic concept for this preparatory course will be introduced, which is applied within a blended-learning environment. For the concept`s design different aspects have been considered, such as changes of the representation levels, comparison of concepts, training of the model understanding as well as multimediality and interactivity.

1. Introduction - Problems with Chemical Formula Language in the Transition between School and University

At school, Chemistry is often considered as „horror-subject“ and hence dropped in the upper levels by most of the pupils.[4] The mastery of the chemical formula language poses a fundamental problem. Many pupils are puzzled by element symbols, stoichiometric coefficients, indices and the formulation of reaction equations with the help of the molecular formula notation.
It is often the case that Secondary Schools start very early with introducing chemical language without all pupils having gained the needed abstract scientific thinking.[5] The problems associated with the formula language are also reflected in a study conducted by our working group. On the basis of the test results, it can be underlined that some freshmen have problems to formulate stoichiometrically balanced reaction equations nor can they draw molecules in Lewis notation or form the correct molecular and empirical formula.
Since this ability constitutes the fundamental basis for a successful study of chemistry the University of Göttingen developed a preparatory course to facilitate freshmen the transition from secondary school to university. This preparatory course aims to review basic chemical knowledge based on a blended learning concept. The facts are to be vividly presented by muldimedia E-Learning modules, so that freshmen can grasp them more easily. Additionally frequently implemented exercises are provided to test the students' current level of knowledge and to consolidate this with the help of detailed feedback.

2. Blended-Learning as effective Method for Learning Chemical Formula Language

2.1 Blended-Learning

Blended Learning is defined as a combination of E-Learning at home and attendance phases with a tutor at university.[6] During the E-Learning phases freshmen acquire the chemical basic knowledge supported by the ILIAS programme which offers them different learning modules for different topics.

Students can choose whether they want to do the exercises alone, in pairs or groups. This allows them to work in their own tempo and if necessary to directly ask questions or to clarify problems of comprehension. Problems that cannot be solved during this phase can be noted down and discussed with the tutor or in plenum in the following attendance phase. Furthermore every of these modules offers a pre- and post-test which give the students feedback about their current level of knowledge and hints at mistakes and misconceptions with possible reasons for them. Three working days are calculated to work through one learning module. After having discussed and solved the problems students had the important facts of the learning modules are revised in groups of four during the explaining phase. In this phase the facts are also defined in more detail and transferred into a broader context. Students are supposed to work independently for most of the time but still have the chance to ask the tutor whenever a problem occurs they cannot solve on their own.
In the following working phase tasks are to be solved alone or in pairs referring to the learning module. Due to the shift in social forms it is ensured that every type of learner is addressed which leads to a better learning result. Hence the procedure of the preparatory course can be described as follows: The first day starts with an introductory seminar in which ILIAS and its handling is explained as well the further procedure. After that the first E-Learning phase starts which covers three working days before continuing with the related attendance day. The timeframe includes all in all three to four weeks.

2.2 Didactical Aspects of learning the Formula Language in a Blenden Learning Course

Especially high standards are demanded for the content of such E-Learning phases. The learning modules are the basis of the preparatory course since students work on them independently. For this reason, the learning modules were developed according to the design principles by Richard E. Mayer, pupils' misconceptions, the Hamburg comprehensibility model and the context orientation.
Furthermore, the modules should have a high level of comprehensibility since occurring questions can only be asked during the first attendance day for that module. It is for this reason that the texts pay special attention to simplicity, structure and organization, shortness and conciseness, and inspiring approaches that were developed by Schulz von Thun et. al.[7] Thus it is possible to convey a great wealth of information in little time. In the introductory course the handling of ILIAS is explained and shown so that an easy operation is ensured. Technical problems are hence minimized which leads to less disturbance in the learning process. The aim of the course is to bring students to the same level of knowledge right at the start of their studies. Due to the large heterogeneity in for example the A-Levels in the different federal states, different teachers and curricula the balancing of such different levels is important.
A multimedia approach is used in order to illustrate the basic knowledge of the formula language. The learning modules contain texts, videos, photos and questions that are interlinked. Thus the formula language can model-like be shown by reference to atoms and molecules with a corresponding molecular formula in a chemical reaction which are marked with different colours in the 'Kugelwolkenmodell' or the Lewis notation. Apart from that, the videos that contain step-by-step explanations of reaction equations and experiments also give some more chemical background knowledge that addresses the visual as well as the auditiv cortex. Also included are basic rules and tendencies within the periodic table with an additional explanation of the element symbols. Detailed comments explain that the symbols do not just stand for the name of the element but also for an atom since pupils often have difficulties understanding the entire meaning of these symbols.[1]
With the help of the blended learning course, learning turns into a self-organized and self-regulated process that is time-independent and partly also location-independent.[7] This way of working requires a high level of self-motivation and hence personal responsibility from the students. However, motivation is kept up by a varying multimedia approach and interactivity. Additionally, the modules are created context-oriented and start with basics and questions based on the everyday life experiences. To avoid that participants of the preparatory course only have to read texts and look at figures questions are asked between the different parts to foster interactivity and independent thinking. Nevertheless students should always questions themselves to make sure that everything is understood. A pre- and posttest is made to give them feedback about their level of knowledge and mistakes they made. These questions are multiple choice questions containing only one right answer. Tests can be repeated as often as wished until a learning success can be seen. A huge advantage is here that learners can work at their own pace and are also able to decide how to use their time.

2.3 Structure of the Preparatory Course

The preparatory course is not just divided into different contexts but also into conceptual levels that were introduced in the Johnstone Triangle.[9] On the macroscopic level as for example in experiments, perceivable properties like appearance, smell, consistency and if applicable taste are described and compared. Normally, considerable differences can be noticed here. To find an explanation for these differences one has to take a closer look at the microscopic level that describes substances model-like on the particle level. Hence atom models are needed to describe and explain what happened. After having established a certain basis that ensures a broader understanding of how an atom is constructed, it becomes more easy to grasp why atoms react with one another. The reason, which is to acquire noble gas configuration, is now more comprehensible. On this basis, the ionic bond can be introduced as an electron transfer reaction. Subsections of the issue are explained (figure 1) before opening up the issue of covalent bonds in which bonding partners share their electrons. Subsequent experiments trigger then a cognitive conflict since some properties of the substances cannot be explained with either of the two known types of bonding. This allows to introduce the metallic bond via metallic properties. After that, selected experiments show reactions between different substance classes. Here, different aspects such as energy, reaction kinetics, redox reactions as well as acid-base reactions are taken into consideration.

Besides the observations on the macroscopic level and the explanations on the microscopic level, element symbols and tendencies within the periodic table are shown and clarified on the representational level. Afterwards, atoms are presented in an appropriate atom model which can be transferred into the Lewis notation. By acquiring gained knowledge about electronegativity ions, dipole molecules and molecular ions can be labeled with charges or partial charges. Lastly, VSEPR offers the spatial representation of chemical structures. The Lewis notation illustrates the basis for chemical reactions, nevertheless. After having formulated a correct molecular formula the entire stoichiometric reaction equation is developed.

The three conceptual levels are linked within the learning modules' topics. Furthermore they are supported by examples and exercises.

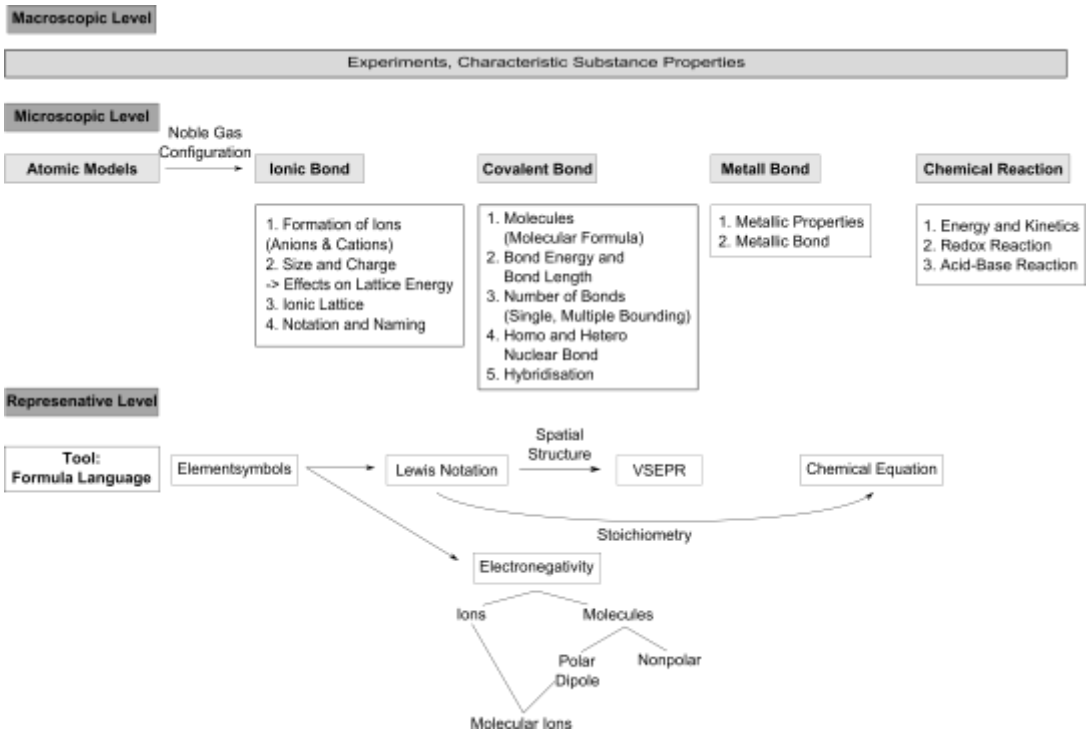

Figure 1: The Structure of the Preparatory Course.

3. Experiences and Outlook

A written post-test at the end of the preparatory course offered the opportunity to compare results with the pre-test that was made at the beginning of the course. Special attention was paid to exercises in which freshmen had to deal with the formula language as for example formulating reaction equations.

After having worked through the modules a considerable improvement became apparent. Chemical substances were labeled with the correct molecular formula and reaction equations were also stoichiometrically balanced. Even reports of tutors based on experiences that have been gained during the attendance days show that questions were rightly answered after having discussed problems that had occurred. Also the given feedback for the content, social forms and the blended learning concept by the freshmen was positive. Constructive criticism was given regarding technical aspects that has to be revised by the start of the next preparatory course.

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