Building bridges to chemistry through biological contents

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ABSTRACT

In contrast to biological contents, chemical contents are still underrepresented in primary schools, although they are implemented in the curricula. This problem is largely due to an inadequate education of primary school teachers and a resulting lack of positive attitudes towards chemical contents and of interest in them. Closely related is a widespread negative self-concept for chemical topics and a low self-efficacy to teach them. In order to address this problem, a university seminar for students of general studies (science and social studies at primary school level) is developed and evaluated as part of a doctoral thesis [1]. In this seminar, biological and chemical aspects of natural phenomena are examined in a near-natural environment. This combination is considered to help transferring the students' positive attitudes towards biology also to chemistry. A combination of different methods is used to evaluate the effects of the seminar, including Own Word Mapping, a self-developed, picture based association test, the Semantic Differential, and a questionnaire with complementary oral questioning. The results indicate that the developed seminar helps students to perceive more connections between chemistry and biology and more chemical aspects in their environment. In addition, the seminar seems to have a positive influence on the unconscious attitudes towards chemistry and on the interest in chemical topics as well as on the self-efficacy concerning the teaching of chemical contents and the self-concept concerning chemistry. Thus the seminar helps to create favourable preconditions for the teaching of chemical contents in primary school as early as during university education.

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Introduction

Unlike the school subject biology, chemistry is a very unpopular one and a negative attitude towards it often lasts during adulthood [2]. There might be a connection between this attitude and the fact that it is difficult for pupils to see links between chemistry and their own living environment. Whereas biology is a subject most pupils associate with nature, chemistry is not [3]. This is not only due to the artificial surrounding of a classroom or a laboratory where chemistry is taught, but also to the chosen topics. Formula, arithmetic operations or technical terms of chemistry lessons are perceived as abstract, difficult and not very interesting. Pupils prefer topics related to their own environment and to natural substances [4]. The negative experiences during their school-days also influence the course of studies of future primary school teachers. They often try to avoid scientific and especially chemical contents during their studies and therefore do not feel adequately prepared to teach related contents [5]. This feeling of incompetence continues and is still present during the time as trainee teachers [6] and their following professional life [7]. Although teachers are aware of the significance of these contents, the lack of knowledge results in insecurities and a tendency to get around chemical topics [8]. Because most primary school teachers prefer biological topics which seem to be easier to teach and less abstract, chemical aspects are underrepresented [9]. This underrepresentation of chemical topics exists despite the specifications of the German curricula for primary schools which largely follow the recommendations of the GDSU (Gesellschaft für Didaktik der Sachunterrichts), a society who promotes general studies and published a booklet in which chemical, biological and physical aspects are shown to be equally important [10], [11]. In order to reduce the problem of underrepresentation, a seminar to encourage and enable students of general studies to teach chemical topics in primary school is developed. An intervention as early as during the university education is chosen, because training for teachers often only reach a very small percentage of the teachers who would need them. The guiding principle of the seminar is a combination of chemical and biological contents in order to transfer the students' positive attitudes towards biology also to chemistry [12]. The seminar takes place in a near-natural environment, in which natural phenomena are examined both from a biological and a chemical angle. The expected outcome of this approach can be summarised in the following research questions:

- Does the seminar help students to perceive more connections between chemistry and biology?
- Does the seminar help students to become more aware of chemical aspects in their natural environment?
- Does the seminar have a positive influence on the students' unconscious attitudes towards chemistry?
- Does the seminar help students to develop an interest in chemical topics and the teaching of them, a positive self-efficacy concerning the teaching of chemical contents and a positive self-concept concerning chemistry?

These questions are examined with different methods which are described below.

Seminar Design

The seminar is designed to have an influence on the foundation of favourable conditions for an increased teaching of chemical aspects in primary school. It takes place in an "open air laboratory with experimental field" (FLEX) of the Institute for Chemistry education at the University of Siegen. It is located outside a small village close to a forest and provides many possibilities to examine natural phenomena. It is an approximately 6700 m^2 large meadow with a shed equipped with experimental material and various tools, a small stream, a pond, flower and herb beds including scented and medicinal plants, fruit trees, a small cornfield, beehives and sheep [13]. It is considered to be a near-natural environment, because nowadays there is no untouched nature, all regions of our world are under the direct or indirect influence of humans [14]. The FLEX is a part of nature with only limited intervention of humans and a rather large biodiversity and can thus be regarded to be near-natural [15]. The participants attend the seminar once a week during one summer semester. In small groups, they first choose specific topics they want to work on (see below) and do some research and experiments on them. After that they develop teaching units for children in primary school and are in charge of the realisation of these units. They are supported by the seminar leaders and their fellow students who also give them feedback. Topics which are chosen by the students are for example "From grain to bread", "Plants and their substances", "From sheep to wool" or "Bees and honey". They all combine chemical and biological aspects and by examining them both viewpoints arise naturally and show that biology is inseparable from chemistry [16]. The topic "From grain to bread", for example, includes the (biological) examination of the cereal plants and the (chemical) study of the mode of action of baking powder and allows the children to make their own bread. Following Martin Wagenschein's recommendations for a successful teaching of scientific subjects, the seminar focuses on only a few exemplary natural phenomena [17]. This is said to enhance a thorough understanding of the examined aspects. The students were encouraged to choose and work on topics on their own in order to make them more self-sufficient, an important aspect of moderately constructivist learning [18]. The students' self-efficacy concerning the teaching of chemical topics is supported by giving them the opportunity to experience a sense of achievement through overcoming difficulties while testing their self-developed teaching units with children [19]. The necessary knowledge to carry out these units has to be acquired by the students on their own (with the help of the seminar leaders) and is thus expected to have a positive influence on their self-concept concerning chemical knowledge [20]. The chosen topics are oriented on the living environment of the children and the requirements of the curricula. They are therefore relevant for the students and help to increase their interest [21]. The development of motivation is dependent on the experience of competence, autonomy and social integration [22]. The students therefore get the opportunity to experience competence and autonomy by carrying out the teaching units while they are supported by their fellow students and the seminar leaders.

Methods

Small groups seem to be favourable to support the objectives mentioned above, therefore only 14 students (divided in two smaller groups) in 2012 and five students in 2013 attended the seminar. Beside the 19 participants, a control group of 19 students of general studies is examined. The members of this control group have the same field of study and attend a different seminar at the university. This seminar is not equivalent to the one in the FLEX, because it would be impossible to transfer the outdoor-conditions into a laboratory or a seminar room. (There could be no exploring of the environment and no independent discovering of natural phenomena.) The control group therefore only serves as a means to show if there are differences between its members and the participants of the FLEX-seminar. A combination of different methods (see table 1) is applied to gain a comprehensive overview of the effects of the seminar and to facilitate the interpretation of the results [23]. All tests are carried out at the beginning and the end of the seminar and with both the participants of the FLEX-seminar and the members of the control group. In the following section the theoretical background and the realisation for each method are consecutively described.

Table 1. Overview of the tested hypotheses and the applied methods

Research questions Does the seminar help students to ...	**Methods**
perceive more connections between chemistry and biology?	Own Word Mapping
become more aware of chemical aspects in their natural environment?	Picture based association test
develop more positive unconscious attitudes towards chemistry?	Semantic Differential
develop interest in chemical topics and the teaching of them, a positive self-efficacy concerning the teaching of chemical contents, and a positive self-concept concerning chemistry?	Questionnaire and supplementary interviews

Own Word Mapping

Own Word Mapping is a special form of concept mapping and is applied to find out about the connections students perceive between chemistry and biology. It was developed by Tiemann to show links between contents which are not necessarily regarded to be connected [24]. Concept Maps were developed by Joseph Novak in 1972 [25] and are a means to give an insight into cognitive structures learners are not aware of and thus can only be gained through indirect methods [26]. Own Word Maps connect two different concepts with the help of terms that describe the nature of these connections. In contrast to other concept maps, the concepts are represented by pictures and not by words, because pictures produce more associations and help the participants to include more of their own ideas. The terms to connect the two pictures can be freely chosen by the participants, because dictated terms would restrict the number and variety of possible connections. The process of the making of the Own Word Maps can be reproduced with the help of lines which connect the terms between the pictures and are numbered chronologically. Participants are asked to find as many paths as possible between the two pictures and leave all unfinished paths. A complex map with many terms and complete paths is thereby considered to show that the participants are able to see many connections between the two concepts. In the present study, two pictures are chosen to represent the concepts chemistry and biology, an Erlenmeyer flask and a flower. These pictures were tested with 14 students and produced sufficient associations. Students are also asked to label the connecting lines with a suitable word, e.g. a verb or an adjective. This helps to define the connections between the terms. In accordance with Tiemann, the maps are analysed by assigning the used associations to different categories. Afterwards, the associations used before and after the seminar are counted and the numbers used by the participants of the FLEX-seminar and the members of the control group are compared. The four chosen categories are biology, chemistry, physics and other, because this method focuses on the connections between biology and chemistry, and it seemed interesting to include the third most commonly taught natural science, physics. The categorisation of the terms is checked through communicative validation [27], by taking into account not only the viewpoint of the evaluator, but also of the students. After that, the number of terms in each category is determined. Because more terms in total do not necessarily mean that students perceive more connections between chemistry and biology, the proportion of terms belonging to the categories in relation to the total number of terms is calculated.

Picture based association test

The picture based association test is used to find out if the students become more aware of chemical aspects in their natural environment through attending the FLEX-seminar. This would help them to find interesting and true to life topics for their future lessons. Because there is no test instrument available for this purpose and a direct confrontation with different natural environments including the recording of spontaneously uttered associations is hardly possible, a test using pictures of near-natural environments is developed. Perception (e.g. of chemical aspects) is an allocation of the things that can be seen to a certain category of things which are already familiar [28]. Associations are involved in the generation of categories, which are classifications of objects or ideas [29]. This is relevant for the seminar because students have the opportunity to become familiar with chemical aspects in their natural environment and thus to broaden their concept of chemistry. An increase of chemistry-related associations would be an indication for this development. The students are confronted with three photos of near natural environments - one after another- and asked to name all associations thy can think of “until they run dry of responses” [30]. The pictures were chosen because they were able to provoke many (natural-scientific) associations and show chalk riffs of an island, a fishing boat on the sea, and a campfire in front of a lake. The utterances are transcribed using a basic transcription method [31], reduced to single associations and analysed by assigning them to the same categories used for the Own Word Maps. The assignment is again checked by communicative validation. Both methods, the Own Word Mapping and the picture based association test, concentrate on associations, one with focus on the connections between chemistry and biology, the other on the perception of chemistry. This is closely related since seeing more connections with chemistry might influence the perception of chemical aspects and vice versa. The combination of different methods to look at similar aspects of the study is used to reduce possible methodological weaknesses [32], and allows a comparison of the results. The new method was tested beforehand with ten experts (people who work in the field of chemistry) and ten amateurs (people who do not have any chemical background) and the results, supported by interviews, indicate that the method is able to show differences in the perception of chemical aspects.

Semantic Differential

The attitudes towards chemistry influence the willingness of primary school teachers to deal with chemical topics and to include them in their lessons. In this context it is interesting to find out if the FLEX-seminar affects the unconscious attitudes of the participants. Allport defines attitudes as follows: “An attitude is a mental and neural state of readiness, organized through experience, exerting a directive or dynamic influence upon the individual’s response to all objects and situations with which it is related” [33]. To test this affective component it would be difficult to ask direct questions which would focus the attention on the problem and thus falsify the results [34]. A proven method to test unconscious attitudes is the Semantic Differential developed by Osgood [35], also called “Polaritätsprofil” [36]. The Semantic Differential was already used in 1991 to test the unconscious attitudes towards chemistry and biology [37] with a repetition of the test in 2013 by members of the Institute for Chemistry Education at the University of Siegen [38]. It is based on a three-dimensional sematic space, in which the origin of the coordinates describes the semantic meaninglessness and the axes are built by pairs of opposite adjectives, e.g. good-bad. These adjectives are usually not used to describe chemistry or biology and are therefore quite suitable to find out more about the intuitive and affective attitudes towards the two concepts. [39]. On a seven-stepped semantic differential the students have to tick how they feel when they think about chemistry and biology. The ten pairs of opposite adjectives are: good-bad, aggressive-peaceful, nice-ugly, useful-harmful, natural-unnatural, ill-healthy, valuable-worthless, unimportant-important, non-poisonous-poisonous, and clean-dirty. Because the Semantic Differential consists of seven steps, four is regarded to be the neutral middle; values higher than four show a more negative unconscious attitude towards chemistry and values below a more positive.

Questionnaire

A questionnaire is used to find out about the students’ interest in chemical topics and the teaching of them, their self-efficacy concerning the teaching of chemical contents and their self-concept concerning chemistry. It is inspired by a questionnaire developed by Möller to examine the interest, self-efficacy and self-concept of primary school teachers concerning physical contents [40]. The items were tested and proved to have satisfactory reliabilities. The items consist of four-point Likert-scales with additional “I do not know”- option (1 = not correct at all, 2 = rather not correct, 3 = rather correct, 4 = completely correct). A four-point scale is chosen to avoid the tendency of many participants to tick the neutral middle of a scale [41]. An example for an item concerned with the self-efficacy is “I am able to teach chemical topics in a comprehensive way”. The questions concern issues related to the teaching units in the seminar and were therefore not relevant for the members of the control group, wherefore they did not take part in this test.

Results

Due to the small sample size of only 19 participants and 19 members of the control group, the reported statistically significant results are not representative. The methods are therefore supplemented by interviews in which the students are asked to find possible reasons for differences before and after the seminar.

Own Word Mapping

To illustrate the difference between Own Word Maps before and after the seminar, two maps of

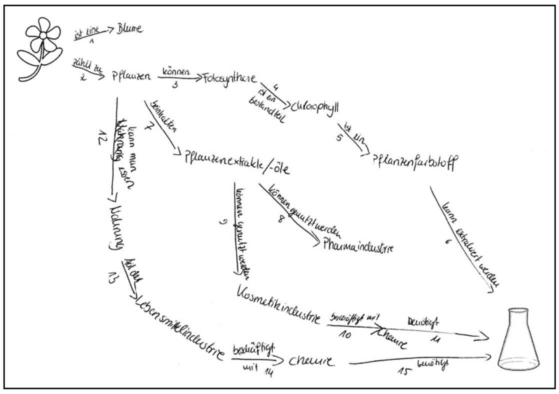

Figure 1. An example of an Own Word Map before the FLEX seminar

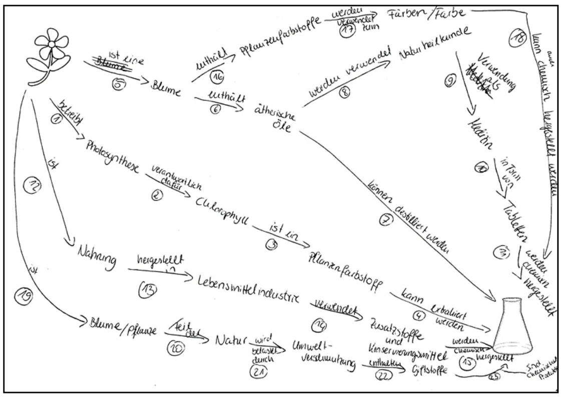

Figure 2. An example of an Own Word Map after the FLEX seminar

a student are shown in figure 1 and 2. Without looking at specific details, the map drawn after the seminar is much more complex with more associations and paths between the pictures. The participants of the FLEX-seminar and the members of the control group use comparable initial numbers of terms in their maps in the categories biology and chemistry (tested with the Wilcoxon-Mann-Whitney-U-test). After the seminar, there are statistically significant differences for the participants of the FLEX-seminar concerning the categories biology ($p < 0.01$) and chemistry ($p < .001$) which the members of the control group do not show. The participants use approximately 5.5 % more chemistry-related associations in the maps after the seminar, whereas the members of the control group use approximately 2 % less of them in the second maps (see figure 3).

Picture bases association test

The initial situation for the picture based association test of both participants and control group are comparable and have no statistical differences regarding the categories biology and chemistry (tested with the Wilcoxon-Mann-Whitney-U-test). After the seminar, the participants show statistically significant differences for the categories biology ($p < .001$) and chemistry ($p < 0.001$) and name approximately 6 % more chemistry-related associations. The members of the control group do not show statistically significant differences concerning the category chemistry, but concerning the category biology ($p < 0.05$) by naming approximately 2 % less biology related associations and 1.6 % more chemistry related associations (see figure 4). As stated above, the differences between the two groups are not representative due to the small sample size.

Semantic Differential

Comparing the values of the Semantic Differential, the participants of the FLEX-seminar show a significantly more positive attitude towards chemistry after the seminar (tested with a t-test, $p < .001$). The mean value before the seminar is 3.2, after the seminar 2.6. This shows that the attitudes towards chemistry are slightly positive even before the seminar but obviously more positive after it. There is no significant difference for biology and also none for the control group.

Questionnaire

The evaluation of the data of the questionnaires indicates that the seminar brings a positive change for the self-efficacy, the self-concept and the interest concerning chemistry and the teaching of chemical contents. With 2.5 being the neutral middle and values above being more positive, table 2 illustrates this development. The influence of the FLEX-seminar is supported by supplementary interviews in which the students identify the FLEX-seminar as the main reason for perceived positive changes. Especially the practical experiences with the children help them to become more confident in their own abilities to teach chemical topics. They also notice that they were able to acquire and understand the necessary chemical knowledge without too many difficulties. Most students enjoy working with the children and notice that they are interested in the taught chemical topics, which also positively influences their own interest.

Discussion

Because this study is carried out with only a few participants, it is important to look at possible influences of the seminar from different angles and thus use several methods. Taken as a whole, the results of these methods indicate a positive influence

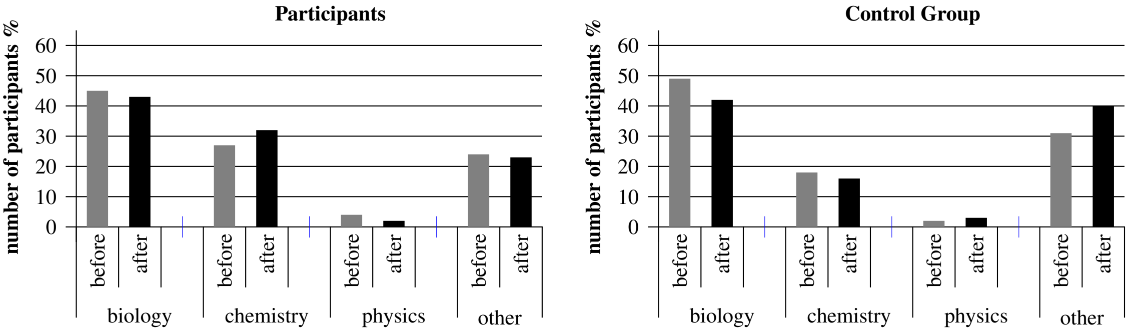

Figure 3. Numbers of associations of the Own Word Maps before and after the seminar

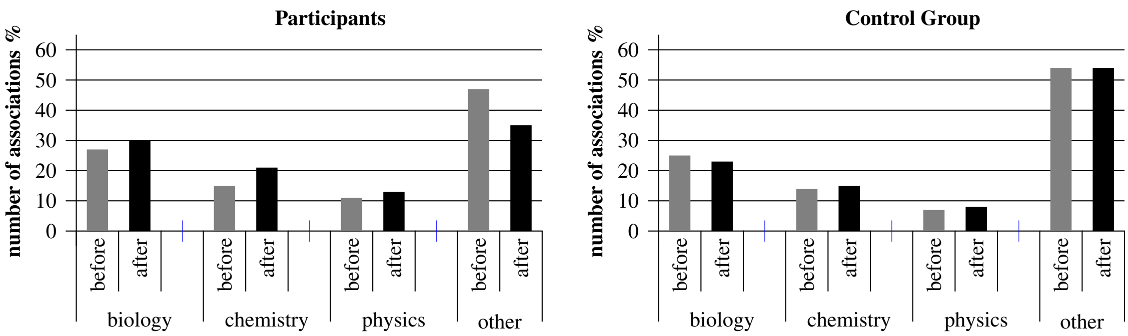

Figure 4. Numbers of associations of the picture based association test before and after the seminar

Table 2. Results of the questionnaire

Scale	M	p
Self-efficacy concerning the teaching of chemical contents		.028
before	2.89	
after	3.31	
Self-concept concerning chemical contents		.013
before	2.56	
after	2.85	
interest in chemistry		.023
before	3.28	
after	3.52	
interest in teaching chemical contents		.002
before	3.23	
after	3.80	

of the FLEX-seminar. A comparison between the results of the Own Word Mapping and the picture based association test - which both focus on associations concerning biology and chemistry - show many similarities. The initial situations of the participants of the FLEX-seminar as well as of the members of the control group are similar and indicate that it makes sense to compare the participants with the control group. As expected, biology gets most associations in both tests. After the seminar, chemistry-based associations increase significantly for the participants but not for the control group. That indicates a positive influence of the seminar on the perception of connections between biology and chemistry and of chemical aspects. Students seem to profit from working with natural phenomena in a near-natural environment, where the connection between biological and chemical backgrounds can be experienced quite naturally. Furthermore, the results of the Semantic Differential indicate an influence of the seminar on the unconscious attitudes towards chemistry. Although the students do already have slightly positive attitudes towards the concept before the seminar, the FLEX-seminar seems to have a significantly positive impact on these attitudes. By looking at biological and chemical aspects at the same time, chemistry is no longer seen as being harmful, unnatural or even poisonous but is for example experienced to be useful to make bread, healthy tea or nice scents. The questionnaires show that students also benefit from the preparation and realisation of teaching units for primary school children. This helps them to develop a more positive self-concept and self-efficacy, because they experience that they are able to acquire and use necessary chemical knowledge. They also take pleasure in this practical work and see its benefits and thus develop more interest in chemical topics and the teaching of them. In summary, the results show a favourable influence of a seminar which deals with chemical and biological topics in a near-natural environment on the ability and willingness of university students to teach chemical topics in primary school. It would be preferable to repeat the study with more participants, but nevertheless the results of the combination of the different methods seems to justify a recommendation of this kind of seminar. If the university students will actually teach enough and sufficiently prepared chemical topics in their future is another interesting research question and would show if the seminar has a lasting effect and is really able to have an influence on the teaching of chemical topics in primary school.

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