"Chemistry is Toxic, Nature is Idyllic" – Investigation of Pupils' Attitudes

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ABSTRACT

Although many natural phenomena are based on chemical processes, most people think that chemistry and nature are strict contrasts, with chemistry as the evil and nature as the good aspect of the scale. At the University of Siegen, we carried out different quantitative and qualitative studies to gain a detailed impression of this antagonism. To get insight into the pupils' unconscious attitudes towards chemistry and nature we collected data with a semantic differential scale. In order to investigate the pupils' view of chemistry and nature we used a questionnaire with open questions. The results reveal the expected antagonism and show interesting ideas of the pupils regarding their concepts of nature and chemistry.

We present an attempt to overcome this antagonistic view: Teaching chemistry in nature can be an opportunity to immediately experience and interpret chemical phenomena in order to close the gap between chemistry and nature and build a personally meaningful, exciting and motivating way to chemistry. In the discussion part, two possibilities for this kind of innovative chemistry education are presented.

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Introduction

Looking at advertising campaigns or talking to people who are without a specific chemical interest often includes the slogan: "No chemistry, please". The same slogan can be found on products such as cleaning tools or food, promoting the quality factor of being organic, natural, or even chemical free.

This advertising message is reflected in a widespread view on chemistry: Words like "chemistry" and "chemical" have a negative connotation; the society is skeptical, afraid and suspicious of chemistry; despite the usefulness of chemical products, catastrophes and accidents remain in the minds of people; consumers do not like "artificial" products and would always prefer natural ones believing that nature and "natural products" are better for a good and healthy life and that chemistry and nature have nothing in common [1]. This view on chemistry could be a reason for the negative attitude of most pupils towards the school subject chemistry.

In contrast, natural scientists have an interwoven view on chemistry and nature, because chemistry is one way to interpret the world by focusing on substances and their conversions. Scientists know that chemistry is everywhere: in flowers, in our food, and in many processes in human life. Therefore, the connection between chemistry and nature is much closer than many people imagine.

Research Question and Hypotheses

To collect data concerning the attitudes towards the concepts "chemistry" and "nature" we carried out studies at the University of Siegen, in Argentina, Ireland, USA, and Germany in 2013. In all these countries, we tested the pupils' unconscious attitudes with a semantic differential scale. Additionally, we asked pupils in Germany how they would define chemistry and nature in order to gain an impression of their view on these abstract terms.

The hypotheses were that (1) chemistry is rated negatively and worse than nature and (2) a connection between chemistry and nature is not perceived by the pupils.

Previous research In the early 1990s, Scharf and Werth investigated pupils' attitudes towards the concepts "chemistry", "nature" and "human" [2] using the semantic differential by Osgood et al. [3] which is a very popular tool to identify conscious and unconscious attitudes [3]. Osgood's Differential is based on a three-dimensional semantic space where the origin of coordinates is as a meaningless space: "[…] an origin, which we define as complete ‚meaninglessness'[…]. If we think of the meaning of any word or concept as being some particular point in this space, then we could represent it by a vector […]" ([5], p. 96). Each of the three dimensions ("evaluation", "potency" and "activity") is associated with adjective pairs separated by a multi-stepped item scale.

Scharf and Werth used a seven-stepped semantic differential and focused on the evaluation-dimension because of its higher universality and better reliability [6]. They found that the concepts "human" and "chemistry" were judged (rather equivalently) as neutral. In contrast, the concept "nature" was judged positively. Scharf and Werth interpreted an antagonistic view of "chemistry" and "nature" and proclaimed that students do not perceive chemistry as a part of nature. So "chemistry" is seen as an artificial and mostly technical construct. Additionally, the concept "biology" was evaluated and it was found that this concept was placed between the concepts chemistry and nature ([6], p. 127)

Methods

Methods for quantitative analysis

To test the pupils' contemporary unconscious attitudes towards the three concepts, we used the described semantic differential of Scharf and Werth [2] in 2013. The used items are shown in Figure 1.

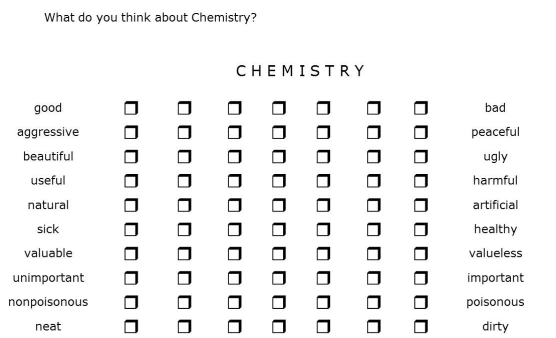

Figure 1. Semantic Differentials based on Scharf & Werth [2] used for testing the image of chemistry.

In total, 822 student of the 8th grade were surveyed in Germany, USA, Ireland, and Argentina in 2013. The sample is described in Table 1. The sizes of the group of male and female students are nearly equal for all countries.

Table 1. Description of the sample; all data from dissertation projects of working-group-members [Spitzer, Hosseini]

Country	Total	Females	Males
Germany	276	129 (46,74%)	145 (52,54%)
USA	274	144 (52,55%)	113 (41,24%)
Ireland	202	100 (49,50%)	102 (50,50%)
Argentina	70	37 (52,86%)	33 (47,14%)
TOTAL	**822**	**410 (49,98%)**	**393 (47,81%)**

For all three concepts, the reliability was calculated and interpreted as good (cf. [7]): Human: $\alpha = .84$; Chemistry: $\alpha = .86$; Nature: $\alpha = .75$.

Methods for qualitative analysis

To gain a more detailed impression of the pupils' view on chemistry and nature, we repeated the study in Germany and additionally asked pupils about their definitions of the notions "chemistry" and "nature". For this study, 249 pupils of the 8th and 9th grade (between 14 and 15 years old) were asked to answer the questionnaire during their chemistry lesson. The questionnaire consists of three open questions to define chemistry, nature and sustainable development, of the above described semantic differential, and of Likert-scaled items of Roczen [8] for testing the pupil's connection to nature. The proportion between boys and girls was balanced; 113 pupils were male, 130 female, and six did not state their sex. The pupils' answers were transliterated, categorised and coded according to the structuring content analysis by Lamnek and Kuckartz ([9], p. 77–84). The inter-coder-reliability (percent of agreement), tested with two additional encoders, who coded 25% random selected material, was good (93%).

Results

Evaluation of quantitative data

In order to analyse the semantic differential we calculated the mean for each scale of the three concepts "chemistry", "human", and "nature" following Werth ([6], [10]). For this purpose, we had to recode the items "aggressive – peaceful", "sick – healthy" and "unimportant – important". The calculated means are shown in Table 2.

Table 2. Means and 95% of the three concepts by countries (Scale from 1 (=positive) to 7 (=negative), center scale 4)

	Chemistry M (SD)	**Human** M (SD)	**Nature** M (SD)
Germany (N = 276)	4.15[1](1.12)	3.45 (0.94)	2.37 (0.81)
USA (N = 274)	3.55 (1.09)	3.16 (1.01)	2.47 (0.82)
Ireland (N = 202)	3.64 (0.99)	2.90 (0.78)	2.41 (0.68)
Argentina (N = 70)	3.61 (0.97)	3.25 (1.02)	2.13 (0.64)
TOTAL (N = 822)	3.78 (1.10)	3.20 (0.96)	2.39 (0.77)

[1]Due to the variance, this mean is significantly different to the middle of the scale four ($t(252) = 2.131$, $p = .034$).

Tested with the t-test, all means are significantly different from the center of the Likert-scale (which is the four; $p \leq .05$). Therefore, it is obvious that all concepts are judged slightly positive with exception of the concept "chemistry" in Germany, which is judged slightly negative. In all countries, the concept "nature" is the most positive, followed by "human" and - as the least positively valued concept - "chemistry". The different answer patterns of the surveyed countries are shown in Figure 2. To present the development between 1991 and today, the original data from Scharf and Werth were adapted and are included in Figure 2.

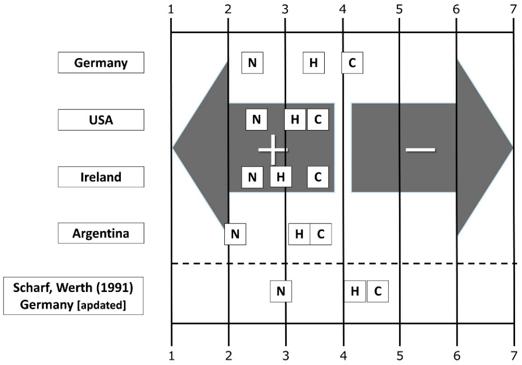

Figure 2. Graphical representation of our own results [11] compared to the key findings of Scharf and Werth [2]. H: human, N: nature, C: chemistry. Middle of the scale is 4.

Using a one-way ANOVA significant differences are detected for the concept "chemistry" ($F(3,754) = 15.545$, $p = .000$), "nature" ($F(3,748) = 3.534$, $p = .015$), and "human" ($F(3,755) = 12.956$, $p = .000$) in all four countries. "Chemistry" is rated most negatively in Germany ($M = 4.15$, $SD = 1.12$), in the most positive way in the USA ($M = 3.55$, $SD = 1.09$). In contrast, in Argentina the concept "nature" is the most positive concept of our sample ($M = 2.13$, $SD = 0.64$), in the USA it is judged in the most negative way ($M = 2.47$, $SD = 0.82$). "Human" is rated most positively in Ireland ($M = 2.90$, $SD = 0.78$) and most negatively in Germany ($M = 3.45$, $SD = 0.94$). Based on Bonferroni-post-hoc-tests there is no difference between the views of the concepts "nature" between Germany and USA ($p = .703$), Germany and Ireland ($p = 1.000$) and Germany and Argentina ($p = .167$). The concept "human" is not evaluated significantly different between the countries Germany and Argentina ($p = .792$), Ireland and Argentina ($p = .056$) and USA and Argentina ($p = 1.000$). You can find a significant difference between Ireland and USA ($p = .028$) [1]. There is no difference between the views of "chemistry" between the countries USA and Ireland ($p = 1.000$), USA and Argentina ($p = 1.000$), and Ireland and Argentina ($p = 1.000$).

In Germany, a significant difference between boys and girls can be found concerning the concept "chemistry" (boys: $M = 3.94$; girls: $M = 4.34$; unpaired t-test: $t(250) = 2.86$, $p = .005$). In contrast to the results from Germany, the girls in Ireland evaluate the concept a little more positively than the boys (boys: $M = 3.81$; girls: $M = 3.44$; unpaired t-test: $t(184) = -2.77$, $p = .006$). In addition, no significant differences between the sexes were found in the other countries. Concerning possible reasons, we like to refer to the discussion of risk taking in chemistry education [12]. In this article, we will not dwell on the sex differences due to otherwise non-existent significances.

In comparison to the German results of the survey of 1991 (cf. [10]), it is obvious that in our survey all three concepts are judged in a more positive way in all countries: today, all three concepts are positively evaluated (with the means being lower than 4). The only exception is the nearly neutral evaluated concept "chemistry" in Germany. The diagram (Figure 2) shows that - in comparison to Scharf & Werth [2] – the change concerning the two concepts "chemistry" and "human" is more positive than the change for the concept "nature".

Evaluation of the qualitative data

The qualitative data allowed a more differentiated impression of the German pupils' perceptions.

The following categories, describing the different definitions of the notions chemistry and nature, arose out of the structuring content analysis (Table 3 and 4).

Table 3. Categories for the definition of chemistry

Question 1: What do you mean by chemistry?

Category	Annotation
Comprehensive concept	Chemistry as ubiquitous principle
Submicroscopic level	Focus on the small(est) particles
Formulas	Focus on formulas, formalism, algebraic etc.
Sequence of different associations	Enumeration of words which are associated with chemistry
Science and research	Focusing on chemistry as science and knowledge acquisition
Investigation of nature and environment	Additional to focusing on research-aspects, direct focusing on nature or environment
Experiments	Direct mentioning of the word "experiment" or circumlocution of the process
Chemistry of substances	Focus on the observation/investigation/science of substances with mentioning of the word "substance"
Chemical reaction	Focusing on transformation of substances
Chemical education	Focusing on chemistry in school – teacher, courses, education etc.

[1] Due to the variance and the resulting shape of the Gaussian normal distribution, in this case there is no significant difference between the means belonging to the countries Ireland and Argentina as well as USA and Argentina but between the two countries Ireland and USA.

Table 4. Categories for the definition of nature

Question 2: What do you mean by nature?

Category		Annotation
In distinction to humans/culture		Nature is namely described as non-human, non-cultural etc.
Comprehensive concept	Terrestrial life	Focusing on “the earth“ or the whole life on earth
	Environment	Direct mentioning of the word “environment” or focusing on our surrounding
	Everything Outside/outdoors	Direct mentioning of the word “outside” or focusing on life outside buildings
	Creatures	In the context of a comprehensive definition, the word “creature” is mentioned
Sequence of different associations	Indiscriminate sequence	Enumeration of words which are associated with nature
	Something green	Mentioning of the word “green” in a sequence of associations
	Something natural	Literal reference on natur/something natural in the sense of “native”
	Enumeration of “nature”-related things	Enumeration of things which normally are labeled as “nature”
Positive or romanticizing assessment		Direct or indirect positive or idealised connotations of nature are mentioned
Humane as a part of nature		Humane, human-made things etc. are explicitly named as a part of nature or are named in a sequence of “natural“ things
Environmental damage		Environmental damage or destruction of nature are named
Religious/divine connection		Explicit link with God or a superior being

The pupils’ answers were coded in units of meanings: a word, a phrase or a whole sentence. It was possible to code units several times (e.g. as a “comprehensive concept” and a “positive or romanticizing assessment”). The numbers mentioned can be seen in the following Figures 3 and 4.

Asked about their definition of chemistry, most pupils give a reference to the categories “doing experiments”, followed by “chemical reaction” and other aspects of “chemistry of substances”. Typical definitions are (translated by the authors): “Mix different chemicals and see what happens” or “Chemistry is when two substances react with each other”. It is interesting that there are only three definitions in which pupils focus on the aspect that experiments serve to acquire knowledge (for example “In chemistry you get new insights into nature, technics etc. with experiments and deliberation”). Many other definitions in these three categories only focus on phenomenological aspects (“exploding test tubes”).

Only few pupils see chemistry as a comprehensive concept and even the fact that chemistry essentially consists of science and research is rarely perceived. The connection between chemistry and nature or chemistry and the environment is mentioned very rarely (eight times in the category “Investigation of nature and environment” and two times related to “chemistry as a comprehensive concept”). If the pupils give an assessment in their definitions, it is always adverse: chemistry is described as “bad”, “toxic” or “threatening”.

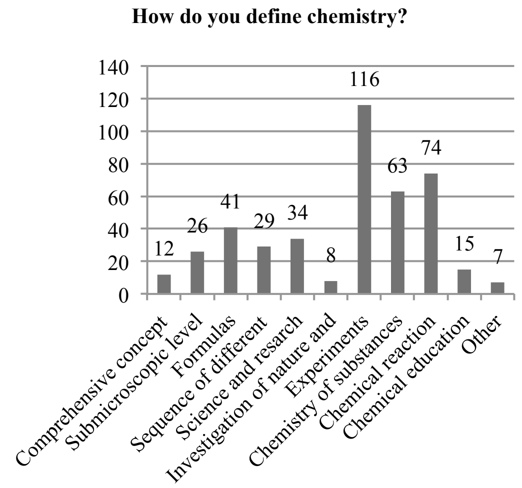

Figure 3. Frequency of different categories of the concept of chemistry.

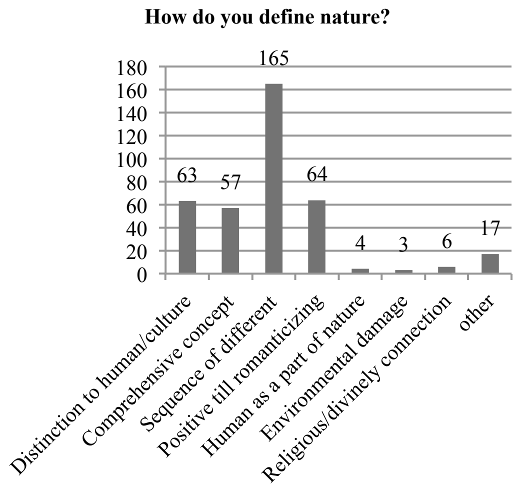

Figure 4. Frequency of different categories of the concept of nature.

The notion “nature” is mostly described by using “sequences of different associations”. Typically, these associations are indiscriminate; they can be short (“trees and plants”) or very long (“quiet, freedom, plants, wood, good air, fresh, natural processes, sunset, sunrise") with up to 18 aspects. These definitions are often linked with a "positive connotation" ("freedom", "beauty", "idyll"), nature is described as "beautiful", "soulful" or "harmless". Even the "romanticizing assessments", as described in former research, can be found in many definitions like "Nature is the most important place and aspect of the world. Wonderful things like humans etc. emerge and have already emerged through nature".

The category "in distinction to humans and culture" ("not created by humans" or "unaffected by humans") is also often used to define nature. The fourth most frequently used definition is the "comprehensive concept" which refers to "everything you can see if you look out of the window" or "Nature is the earth, as it is".

Discussion

With reference to our hypotheses, we ascertain the following:

(1) "Chemistry" is assessed worse than nature, but is seen rather neutral then bad. Some reasons for this slightly positive attitude towards chemistry could possibly be: (a) the "green chemistry"-initiative (cf. [13]), (b) greening chemistry campaigns of leading chemical companies, (c) image campaigns of the chemical industry like "We create chemistry" by BASF[2] or (d) an increasing number of popular science magazines in the media.

(2) Most pupils do not perceive a connection between chemistry and nature.

The pupils' answers to the open questions differentiate these findings. However, these qualitative data refer only to Germany.

Using the categories "chemistry of substances" or "chemical reaction" to define chemistry is probably obvious for pupils in Germany because the definition of the new subject chemistry is often addressed in the first chemistry lessons in the 7th grade. After many discussions in the last years, more and more experiments are carried out in chemistry lessons in Germany, which might explain the frequency of definitions from the category "experiments". Nevertheless, the fact that the relevance of experiments (to gather knowledge, proof hypotheses etc.) is not perceived by pupils, needs to be viewed critically.

Only very few pupils have a comprehensive view on chemistry and many do not see that chemistry is used to investigate nature and the environment. This indicates that the assumed gap between chemistry and nature or chemistry and the everyday life of pupils exists and could not be closed to this day, in spite of popular concepts like "Chemistry in Context", the German counterpart of "Salters advanced chemistry". This might indicate that the knowledge-based linking of chemistry subjects and everyday life is not sufficient. According to well-known psychological research, it could be interesting to integrate students' emotions and experiences in this linking-process. Suggestions to integrate these ideas will be made later in this article.

The frequent use of associative sequences to define nature can be interpreted in different ways:

On the one side, it could imply that the notion nature is connoted more emotionally than chemistry. A higher emotional affinity could induce a more extensive framework of associations. On the other hand, the notion nature is present for pupils since their early childhood, while the not-sensual perceptible notion chemistry is brought to their attention much later. Therefore, the larger number of references to the notion "nature" could simply indicate more knowledge and experience. The interpretation of a more emotional connotation could be supported by the fact that there are so many positive assessments of nature.

The circumstance that nature is seen in a very positive way could perhaps be used to operate against the often described negative attitude of pupils towards the school-subject chemistry and the concept "chemistry". If you link chemistry and nature based on knowledge, emotions, and experiences, it (1) can help to close the gap between nature and chemistry (2) could mediate a transfer of the positive emotions that are connected with nature to the rather unpopular subject chemistry.

Implementation of nature, emotions, and experiences in chemical education

At the University of Siegen, we are developing different concepts considering the aspects mentioned above. The concept "…natürlich Chemie!" [14] (including both "natural chemistry!" and "of course chemistry!) comprises teaching chemistry in natural contexts and in near-natural environments, to (1) help to develop basic concepts of chemistry, (2) inspire and maintain interest in chemistry and (3) expand the view on chemistry. Furthermore, it is easy to integrate aspects of Education for Sustainable Development (ESD) into this concept: the importance of acting sustainably and being responsible for the environment is emphasized when nature is seen as the substantial basis of life [11]. Three units are developed so far: (1) More than a tasty food: chemical investigation of milk, (2) Sweet and interesting: honey within the focus of chemistry and (3) About risks and side-effects: natural medicine [15], [16].

The Chem-Trucking-project (cf. [17], [18]) is based on a Piaggio Apecar equipped with variety environmental analytics equipment (photometrical and sensorial measurement equipment) to carry out

[2] For example, see https://www.basf.com/de/we-create-chemistry/we-create-chemistry-campaign.html.

water and soil analyses outside the classroom. We give students the opportunity to experience environmental chemistry in real situations with authentic problems, such as investigating the effect of liming in the woods or the problem of increased pH-values in lakes during summer. To give students a genuine insight and to spark their interest in the work of scientists, we also cooperate with the regional environmental analytic laboratory HUK Umweltlabor. In this way, we try to focus the vocational orientation of students on scientific professions. According to the relevance-model of Stuckey, Hofstein, Mamlok-Naaman, & Eilks [19], the vocational dimension is one of three dimensions helping to illustrate the relevance of science education. The effect of this project is currently evaluated.

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