Computer-Based Learning in Chemistry Classes

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Currently not many people would doubt that computers play an essential role in both public and private life in many countries. However, somewhat surprisingly, evidence of computer use is difficult to find in German state schools although other countries have managed to implement computer-based teaching and learning in their schools. This paper attempts to understand the reasons for this phenomenon and to show that more research and development on computer-based teaching and learning should be done. It starts with some comments on the importance of computer-based learning, followed by a description of the development of ICT in education since the 1990s in Germany and the general situation at public schools. After focusing on the frame of educational policy in Germany, the situation in schools, including the person of the teacher, is then reflected upon and compared to the situation in other countries. Finally, current developments of computer-based learning in chemistry education in Germany are discussed and a frame of further research is proposed.

Keywords: STEM, secondary students, assessments, gender, school category

INTRODUCTION

Computer related abilities are vital qualifications in technological societies such as Germany which depend on quick and easy access to information. In professional as well as private contexts, computers play an important role in generating and distributing information and for the purposes of communicating. Therefore, the abilities to work with computers in a goal-oriented manner, to reflect upon the potentials and dangers of different aspects of computer use, and to be able to choose which software is best suited to what task is crucial for both professional and social development. Computer-based learning, which involves acquiring all these abilities and includes general media competence, is an essential part of computer literacy. Pupils need to be given relevant education in computer literacy in order to play an active and productive role in the future. Computer literacy should, therefore, be seen as an integral part of general education. The computer literacy that is taught at schools should serve as basis on which the pupils would be able to further develop their own particular abilities. This implies that, ideally, all subjects taught at school have a component which actively teaches computer literacy.

Science teaching in general and chemistry education in particular can include aspects such as data logging and data handling, working with visualisations, or producing chemical drawings. The potential to use different types of visualisations (e.g. static, dynamic, and interactive) is unique in chemistry and should be included in day-to-day teaching. Of course, proper chemical education also needs to include other elements, like practical work, that support the students' learning about chemistry concepts and their application in everyday life. Computers can support and enrich practical work because it is known from research that computer-based learning in chemistry can foster the understanding of chemical concepts also in the laboratory environment. Therefore, computers should be, like experiments, one of the supporting pillars of a modern chemistry education. However, do teachers provide opportunities for their pupils to take part in computer-based learning, and if so, how are they

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integrating computer in their teaching? What is the current situation in German schools? This article discusses the traditions, conditions of and current developments in computer-based learning.

Some Remarks on the Relevance of Computer-based Learning

Since the late 1980s, research has been conducted into computer-based teaching and learning. Researchers from media pedagogy and domain-specific education (e.g. chemistry education) as well as general educational and psychological researchers attempted to discover the advantages and disadvantages of using computers in learning environments. At the beginning of computer-based learning, many assumed that computers would, sooner or later, replace teachers and that children would only learn through computer related technology. However, a more realistic view of the implementation of using computers in teaching and learning processes is now the norm. Admittedly, the potential of computer use in education was long overrated. The current concepts of computer-based learning assume that any computer training needs to be carefully planned and linked to concrete tasks the students have to do. As with any other media, computer use has to be justified and reasonable.

Mayer (2003) did much research to discover which setting is best for a computer-based learning environment. He introduced the widespread multimedia theory in which he identified several effects: the multimedia effect, the coherence effect, the spatial contiguity effect, and the personalization effect (Mayer, 2003). Sweller's cognitive load theory (1988) gives an explanation as to why students with above average abilities benefit more from computer-based learning than those with lower abilities. This has important consequences for the design of digital visualisations. That is, they should be carefully designed in order to avoid excessive demands being placed upon the learners. Mayer and Moreno (2003) offer pertinent advice on how this can be done.

Researchers are familiar with reading studies that show the positive effects of computer-based learning and others which declare the opposite to be true. In order to make informed decisions, it would be helpful to have more information about the settings of the studies. Often, no information is given as to how the lessons were designed and what exactly was done on the computers. In some cases, even the questionnaires that were used are missing. However, this information would give an explanation as to why sometimes computers have a positive effect, sometimes not. Like any other media use, the methodology used to implement it in the lesson is crucial for successful learning. The work with the computer has to be prepared and this has to be accompanied by tasks. After the computer work, the results have to be discussed.

To conclude, principled computer-based learning remains elusive, although it is accepted that, with regards to chemistry, computer-based learning has the potential to foster meaningful learning (Bingimlas, 2009). For example, digital visualisations can show the sub-microscopic level of a chemical reaction or show the spatial appearance of a molecule. This may help the students make a connection between their observations on the macroscopic level and on the molecular level (Barnea & Dori, 2000). Additionally, animated visualisations can show dynamic processes in a much more relevant way than static visualisations (Reid, Wheatley, Horton & Brydges, 2000). Taking these considerations into account, computers should be an integral part of modern chemistry education.

Computer-based learning in Germany since the 1990s

To better understand the current situation regarding computer usage in science classes, the development in Germany needs to be discussed. During the 1970s, the first ideas on the implementation of chemistry related computer-based learning were developed and published in German chemistry education journals. One of the

first publications was written by Martens & Hallstein (1976). At that time, it was nine years since the first articles on computer-based learning had appeared in the *Journal of Chemical Education* (e.g. Bard & King, 1965; Casanova & Weaver, 1965; Emery, 1965; Zajicek, 1965). It can therefore be seen that this development in Germany started much later.

In Germany, the publications during the 1970s and 1980s focused on calculations; the development of computer-based learning materials in Germany started at the beginning of the 1990s. Over the next fifteen years, many initiatives, individuals and chemistry educators at universities started working on the topic and developed a great amount of material (Dori, Rodriguez & Schanze, 2013). Since the mid-2000s, the number of publications has decreased. Unfortunately, the reasons for this cannot really be described concretely, but only through the use of examples and remain vague because very little, if any, information exists to explain why this has happened.

Much of the learning material has been developed, and published on personal web pages, to enable chemistry teachers to integrate the materials into their lessons. Chemistry educators expected that teachers would then become active and develop strategies in order to use this digital material in their schools. However, they became aware that teachers had to overcome many difficulties in order to use the materials. (This is later described in more detail.) Most of the teachers avoid using computers (Mumtaz, 2000). Some reasons for this are lack of teaching experience with ICT, lack of computer availability, lack of resources and lack of on-site support (Mumtaz, 2000; Bingimlas, 2009). Additionally, there are only few workshops offered for teachers that cover subject related computer-based teaching issues. And when workshops are offered only very few teachers attend. Another reason for the lack of computer use in chemistry lessons might be the fear that the computers will replace the experiment. And, often, teachers simply do not know how to implement computer-based learning phases (Pietzner, 2009).

German physics educators are also involved in computer-based learning. The main focuses of computer use in this subject are data logging and data processing. In addition, interactive monitor experiments (IBE = *Interaktive Bildschirmexperimente*) are extremely well known. An IBE consists of a series of pictures of an experiment that can be manipulated with the mouse. Depending on the mouse action, different pictures are shown. This gives the impression of a movement, or a changing signal on a measurement device. These data can then be analysed, and the students can independently discover a physical law (Kirstein, 1999).

One example of an IBE is finding the centre of mass of an irregular body. The body has several holes where it can be suspended on a horizontal bar. Using the mouse, the students can choose the hole, and then they can let the body swing. If the students suspend the body with the hole in the mass centre, the body will not swing, but remain in the position where the students have placed it. This IBE and three more examples can be found at the homepage of the Department of Physics Education at FU Berlin (FU Berlin, 2013).

Even after much research and development of material for teaching chemistry, computer use in chemistry classes in Germany is still rare and has not evolved since the 1980s (Flintjer, 2011). One problem when conducting research on computer-based chemistry learning is that it is an interdisciplinary topic. For example, results from research dealing with electrochemistry are not necessarily comparable with results obtained in organic chemistry. Additionally, different topics need different visualisations, and therefore the results may be different. Therefore, the field of computer-based chemistry learning is very heterogeneous.

On an international level, computer-based teaching and learning seems to be investigated in the similar way and under the same conditions. Work by a few authors such as Dori et al. (e.g. Dori & Sasson, 2008; Kabermann & Dori, 2008; Barnea & Dori, 1996, 1999, 2000; Dori & Belcher, 2005, Barnea, Dori & Hofstein, 2010) and Lawless et al. (e.g. Lawless & Brown, 1997; Lawless, Mills & Brown, 2003; Recker, Walker & Lawless, 2003; Smolin & Lawless, 2003; Lawless & Pellegrino, 2010) appears many times and the authors frequently publish on this topic. For these authors, the computer and its uses is their field of research. However, it is the norm that researchers follow other fields of research, and if they publish on uses of computers in chemistry classes, they wanted to discover whether students can benefit from the computer in their particular fields. For example, Sanger and Greenbowe (2000) investigated students' misconceptions in electrochemistry. In 2000, they published a study in which they investigated whether animations could help students to overcome common these misconceptions.

The Perspective of Educational Policy in Germany

In light of technological developments and the increasing relevance of computers in daily life, the Standing Conference of the Ministers of Education and Cultural Affairs of the Federal States in the Federal Republic of Germany (KMK) published a declaration in 1995 (KMK, 1995). In this declaration, a framework for media education in schools is given. It begins with a description of the relevance of digital media in modern society and stresses the importance of media education for the students. The KMK argues that a proper media

education is an essential part of education at home, but is also an important goal for school education. Media education at schools has various aims, for example, the students should be able to: orientate themselves in the world of media; move freely in a world of media; and reflect upon information critically. The KMK suggests that schools have to teach the students to be open-minded towards the media world. The KMK also mentions different options that can be included in media education, regarding both the organisational level (e.g. timetable, equipment) as well as the level of lessons. Interestingly, although some types of media are explicitly named (e.g. films, pictures and school libraries), computer related media education is not among them.

In 1998, the KMK published a further declaration covering the role of media education within teacher education (KMK, 1998). Here, new media are explicitly named. The KMK defines general requirements for media pedagogical teacher education. It is stressed that the curriculum must include subject-specific media education for each individual subject. Future teachers should be trained and qualified to use new media in teaching, to plan and to arrange media based learning, and to reflect upon media use.

In addition, the KMK defines three key aspects within teacher education: general knowledge (e.g. media socialisation and analysing media); subject-related didactics (e.g. using new media in chemistry lessons); and interdisciplinary aspects (e.g. how to foster interdisciplinary learning by using new media). Finally, the emphasis on the second phase of teachers' education in Germany (a one and a half year teacher trainee program on the job, ending with a federal examination) is the improvement of qualifications for the future teachers.

After this declaration, it took fifteen years until the KMK again focused on media education at schools (KMK, 2012). Compared with the first declaration in 1995, the declaration of 2012 is much more concrete and has a focus on digital media. It defines several courses of action within the schools, addressing different levels such as the curriculum, school development, technical equipment, teacher education and quality management. In contrast to the declaration of 1995, it is emphasized that parents and schools are equally responsible for sustainable media education. Media education is seen as mandatory task and should be constantly present in every aspect of schooling.

Looking at the development of the declarations, they make school authorities and each teacher responsible for media education. From the perspective of chemistry education, the teachers should include digital media in their teaching in a reasonable and targeted manner. It is clear, however, that the use of computers should not only be included for the sake of using computers. The

use of computers always has to fulfil a certain goal. This responsibility should also be mentioned in the core curricula of the respective subjects. In 2004, the nation-wide standards for chemistry were published (KMK, 2004). Over the following five years, all Federal States developed their own core curriculum for every school type in general education (i.e. elementary schools and the different types of secondary schools) from the national standard. The Core Curriculum for Chemistry for Lower Saxony Grammar Schools (Ministry of Education of Lower Saxony, 2007) is now taken as an example.

In a general introduction of the relevance of the Natural Sciences for general education, it is stated: "By encouraging the students to use media diversity in science education, the subjects biology, chemistry and physics contribute to the competent handling of media" (Ministry of Education of Lower Saxony, 2007, p. 8). For chemistry, the use of different media is mainly related to the reflection of media content regarding the correctness of the material and/or to the use of molecular models as media. As a result, using computers in chemistry education is emphasized in the general framework of science education, but this is not transferred to the actual chemistry curriculum. Therefore, teachers are not supplied with any guidelines and strategies as to how to implement computer-based teaching and learning in a sustainable and enriching manner.

Additionally, the schools are asked to develop their own media education concepts. This concept development clearly greatly depends on the effort and knowledge of the respective teachers which would mean that the concept varies from class to class and among schools. Some schools introduce the students, often during project weeks, to working with office software such as text processing software and spreadsheet programs. No further time is then spent on these topics and the students are supposed to independently practice and improve upon their work with the computer. Other schools design strategies on how to involve computer use in everyday teaching and make much effort to find and develop suitable teaching materials. Therefore, the media education of the students greatly depends upon the effort of the teacher, and the students are given relevant media education more or less by chance.

Finally, the necessity of the development of a core curriculum focusing on Computer literacy should be seen as a given. In 2007, in the USA, The International Society for Technology in Education published the second edition of a National Educational Technology Standards (NETS) for K-12 students (ISTE, 2007) and standard also describes the typical competencies expected of literate students of different age groups (ISTE, 2009). This standard was incorporated into the curricula by almost every state in the United States of

America. Unfortunately, Germany has not yet succeeded in developing a mandatory curriculum for computer education.

The general Situation at State Schools

Although educational policy emphasises the importance of computer literacy, there is a lack of respective initiatives on the level of the curriculum. This circumstance is reflected in the situation of computer-based learning that can be observed at schools. In 1996, the German Ministry of Education and Research and the Telekom Foundation founded the association *Schulen ans Netz e.V.* (Schools go Online). The goal of this association was to provide high speed internet access to every state school in Germany. At that time, only 800 state schools had internet access. In addition, the association offered professional development for teachers which focused on learning using the internet and conducted some research on computer-based learning. By 2007, all state schools in Germany had high speed internet access, and, therefore, *Schulen ans Netz* had achieved its aim. The Telekom Foundation then withdrew from the association. Finally, in 2012, Schulen ans Netz was disbanded. Even the homepage of the association is no longer active (Wikipedia, 2013).

The disbandment of Schulen ans Netz is symptomatic of the situation of contemporary media education at state schools. Stakeholders increasingly think that computer-based learning at schools is no longer an issue and that implementing computer-based learning at schools no longer needs support. However, teachers and schools still need support on different levels: Equipment, professional development, and strategies for computer-based teaching and learning which include good practical examples.

When investigating the equipment available, the situation at schools seems to be very heterogeneous. As previously mentioned, no standards for computer literacy have been defined by education policy, and therefore the schools do not need to have a guaranteed minimum amount of equipment. The computer equipment available depends on the financial capabilities of a school's governing body. In general, schools are financed by cities and municipalities; cities with a high tax income can afford to keep the school's equipment more or less up-to-date, whereas others can only use outdated computers. Additionally, the amount and quality of the equipment depends on the school type (KMK, 2003, p. 121).

The KMK publishes a biannual education report. The first one was published in 2006, and in this first edition the role of computers for teaching and learning was emphasized (*Autorengruppe Bildungsberichterstattung*, 2006). The following reports did not, and still do not include this topic anymore, therefore, the data of 2006 must still serve as basis for the discussion which follows, together with the education report of 2003 (KMK, 2003, p. 120). Secondly, only general aspects can be discussed because no information regarding the individual subjects was given in the report.

State schools, at all levels, are now equipped with computers. The ratio of students per computer (one computer for 24 students) is the highest at elementary schools. At secondary schools, the ratio is 16 students per computer (KMK, 2003, p. 118). The question that now arises is how often the computers are included in teaching. Here, the report (KMK, 2003) uses the data of the PISA 2003 study; Table 1 shows the results.

Wirth and Klieme (2002) evaluated the data from PISA 2000 and obtained a similar result to that of PISA 2003. Computer use in German schools is the lowest among European Union members and only Russia has lower percentages. The students are very interested in learning by using computers, but they rate their computer-based skills as relatively low. These results correspond to that of a study of Hiller (2012) who reports that 49 % of the students use computers at home for their school related work, but only 16 % use them frequently at school. This imbalance becomes even worse if this percentage is compared to the general computer use outside the school, which is 90 %. Computer use does not, of course, correlate to the quality of teaching, but it has to be stated that goal oriented computer use at school can lead to proper computer literacy. Further, Wirth and Klieme (2002) could demonstrate that the socio-economic status of the family has a greater influence on the students' computer literacy than the school. Therefore, students with a low economic status are in danger of not becoming properly computer literate which can lead to a lowering of work related opportunities.

It is, of course, difficult for schools to keep pace with the rapid developments in technology. For example, German schools have less equipment and software compared with the international average of schools' equipment (KMK, 2003, pp. 117-122). Some schools have an administrator, who cares about the equipment, but often one teacher is responsible for the one or two computer rooms at the school; he or she has

Table 1. Computer Use at Schools in Germany, the EU, and on international level (KMK, 2003).

Computer Use in Class	Germany	European Union	International
Never	37 %	16 %	No data
Never or less than once a month	51 %	22 %	24 %
Every day	18 %	42 %	38 %

to install software and keep the equipment in running order. Therefore, only 'standard' software is installed, and chemistry teachers depend on the commitment of the nominated person when they need special software to be installed. Additionally, the computer rooms often need to be booked weeks ahead of time. In these cases, the lessons have to be planned according to the possibility of access to the computer room. All this can lead to the attitude that using the computer room adds to a teacher's workload (KMK 2003, p. 122). In chemistry classrooms, access to computers and a projector is not widespread. The provision of these is dependent upon the head teacher and/or the commitment of the chemistry teachers.

This leads to the second problematic aspect: the professional development of chemistry teachers. In Germany, professional development for teachers is not compulsory, unlike other countries such as, for example, Japan (Fernandez, 2002; Shimahara, 1998). Therefore, only teachers with high motivation will attend professional development courses although several chemistry educators offer professional development for chemistry teachers in the field of computer-based learning.

On these courses, teachers are given training in how to use chemistry software and how students can meaningfully learn with computers. However, these courses are not offered throughout the country. The Centres of Professional Development for Chemistry Teachers which are supported by the German Chemical Society offer such courses, but only seven such Centres exist. And, because professional development is voluntary, these courses are few and far between. In addition, at teacher training institutions subject related computer-based learning courses can only be found at a few universities, as can be seen in the respective study programmes on the homepages of the universities. Many students leaving university and entering the teaching profession are not trained to include computers in their teaching. They will, therefore, use a strategy of avoidance which may lead to the computer anxiety observed in several studies (e.g. Beckers & Schmidt, 2003; Yaghi & Abu-Saba, 1998; Russel & Bradley, 1997a, 1997b; Rosen & Weil, 1995; Koltrik & Smith, 1989).

Research on computer-based teaching in Germany

As can be seen, the formal conditions for computer related education in Germany remain intangible when the day-to-day teaching is investigated. This is reflected by the studies on computer use in the classroom. Regarding computer use in German schools, Schaumburg (2003) explains that systematic data have been collected since 2001. One example is the SITES

M2 study (Schulz-Zander, 2005) that investigated computer use using case studies. The main components of computer use are shown to be information search and the production of a media product, for example, presentations. The software used at schools is mainly productivity tools (i.e. word processing programs, spreadsheet programs, presentation software), e-mail and search engines. There is no difference between the different subjects (Schulz-Zander, Dalmer, Petzel, Büchter, Beer, & Stadermann, 2003). Special learning software or even special software such as tools for data collection only play a minor role and could only rarely be found (Schaumburg, 2003). These results are similar to findings on the international level: In class, the computer is more of a tool than a real means for supporting learning (Collis & Carleer, 1993).

These results also mirror the software facilities that are available at schools. They usually do not possess special software (Anderson & Ronnkvist, 1999). Therefore, they are not able to include subject-related programs and have to depend upon the more common office related products. Regarding the class arrangement, the students usually work on the computer alone or in pairs. The computer is sometimes used to give additional support to less capable students (Veen, 1993).

Computer Use by German Science Teachers

After looking at computer usage in a more general way, the focus is now turned on the situation in science classes. In 2006, a study among science teachers in Lower Saxony was conducted (Pietzner, 2009) to find answers to the following questions:

What attitudes do science teachers have towards using computers in their science classes?
How do science teachers use computers when they do so?
Can differences be observed when linked to the teachers' gender, years of experience, and subject?

Approximately 1,200 science teachers from lower and upper secondary schools participated in the study; 55 % males and 45 % female. All three science subjects were almost equally represented (i.e. biology: 36.4 %; chemistry: 33.3 %; physics: 30.3 %).

It was discovered that science teachers rarely use computers in their classes: Sixty percent of the teachers never use computers in their science lessons. This group mostly consisted of female teachers which might indicate that female teachers in particular are less able to provide a proper media education to the students. This result corresponds with Rosen and Weil (1995) who found the same was true in the United States.

Regarding the different subjects, interesting differences can be found: Table 2 shows the result of a factor analysis which evaluates the different classroom formats used for computer-based learning phases in

Table 2. Rotated component matrix of the factor analysis looking at the class arrangement. Only factor loadings >|0.30| are shown.

	Biology Factor		Chemistry Factor		Physics Factor	
	1	2	1	2	1	2
Teacher Centered		-0.812		-0.780		0.858
Single/Partner Work		0.837		0.778		-0.874
Group Work		0.449	0.405	0.626	0.598	0.340
Learning at stations	0.576		0.615		0.767	
Giving Help	0.808		0.737		0.773	
Additional Tasks	0.783		0.806		0.747	
Variation accounted	28.0 %	27.4 %	29.3 %	27.2 %	35.6 %	27.3 %
Cumulated share	28.0 %	55.4%	29.3 %	56.5 %	35.6 %	63.0 %
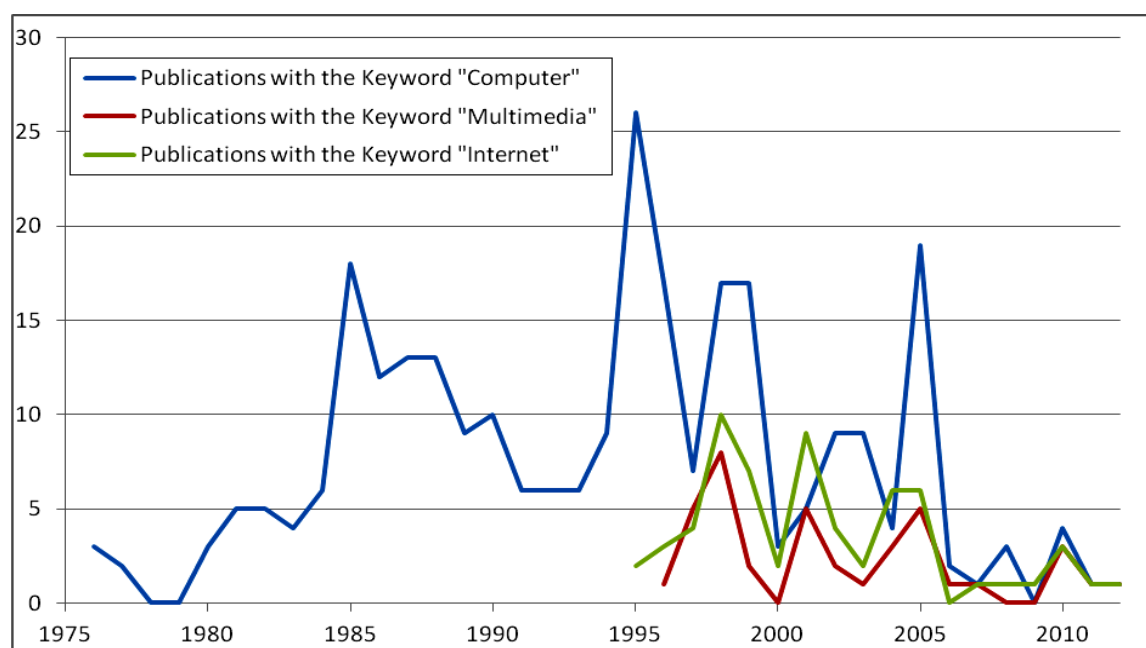
Figure 1. Result of a database search in German journals for chemistry teachers

biology, chemistry, and physics classes. What is of note is that physics teachers use a different strategy from that of biology and chemistry teachers. In physics classes, computers are used mainly in teacher-centred classes (Pietzner, 2009).

In Lower Saxony, the most common software used in science education is Internet search engines, followed by the use of animations and simulations. Data acquisition and other applications (i.e. WebQuest, 3D molecule visualisations, mind maps/concept maps, learning units, chat/forum) play a much smaller role. The percentage of use of animation/simulation, chemical sketching software, chat/forums and e-mail does not differ between the subjects. Data acquisition is used significantly more often in physics classes than in biology and chemistry. Internet search and the use of WebQuests, 3D molecule visualisations or learning units are used significantly less in physics than in biology and chemistry classes.

In 2012, twelve chemistry teachers from lower secondary level were interviewed to obtain a clearer picture of the teachers' attitudes and utilization profiles (Barwinski, 2013). The results show that the computer only plays a minor role in chemistry classes although the teachers have positive opinions of computer-based learning. However, teachers still feel uncomfortable using computers in class. Approximately two thirds of the participants can be designated avoiders and do not use computers at all. Therefore, since the study of Rosen and Weil (1995) and Pietzner (2008) no relevant development can be observed.

Initiatives in Germany – a short overview

This section discusses how chemistry teachers can receive support and where they can obtain good practice examples. Journals and internet portals targeting teachers form the basis of the information obtained. The number of publications in German journals, written

specifically for chemistry teachers, might serve as indicator of the importance of a topic. To obtain an overview, the database DChemLit (2013) was used to search in the respective chemistry teacher journals. For the search, the keywords Computer, Multimedia, and Internet were used. Figure 1 shows the results.

The first publications covering computer use in chemistry classes were already being published by the mid 1970s, but they were still more focused on the use of calculators. Many papers were published in the 20 years between 1985 and 2005. In 1985, 1995, 1998 and 2005, special issues of journals were published and, therefore, the number of publications increased.

The keywords Internet and Multimedia started to appear in the mid 1990s. One reason, of course, is that the World Wide Web was established at the beginning of the 1990s. Starting only with a dozen web pages, for example, from CERN, University of Erlangen-Nurnberg, NASA, and TU Munich, the World Wide Web rapidly expanded. However, it took about five years until sites containing material suitable for teaching were available. The first article labelled *Internet* in the database was published in 1995 by a professor from Erlangen University and the title was *Chemistry on the Internet* (Ihlenfeld & Gasteiger, 1995). Subsequent publications discussed whether or not teachers should have an internet access and/or how to obtain information from the internet. Other publications containing the keyword *Internet* described concrete implementations of the Internet into the chemistry curriculum. Publications containing the keyword *Multimedia* mainly discussed the software that could be used in chemistry classes and proposed different ways of using them.

In Germany, only a few initiatives that work on different fields of computer-based teaching and learning can be found. The following section gives a summary of the different activities in Germany.

Learning environments, WebQuests

One of the projects with a long Internet history is CHEMnet (see Figure 2), an initiative from the Leibnitz Institute of Science Education (IPN) in Kiel. The focus of CHEMnet is general and inorganic chemistry, and the content is available in German and in English (Nick, Andresen, 2005; CHEMnet, 2013). The content is not freely available, but free access can be obtained after registration. The main development took place in the late 1990s until approximately 2005, but it is still updated frequently. Using log data of the users, an evaluation of CHEMnet was conducted to discover who uses CHEMnet and what content is most frequently read. Looking at the content, CHEMnet is mainly text based. Additionally, some videos of experiments, red/green pictures and 3D crystal structures of important inorganic compounds in the VRML format are available. Unfortunately, VRML is outdated and CHEMnet has not yet been updated to use Jmol or JSmol.

Currently, new learning environments for chemistry are being developed by the Chemistry Education Group at the University of Bremen. This group has worked among others on a multimedia learning environment to prepare students for the transition from lower to upper secondary education (Krause, Kienast, Witteck & Eilks, 2013). Furthermore, many learning environments are available e.g. on the particulate nature of matter or bionics that replaced technically outdated HTML based learning units. The new versions are now based on Prezi technology (Eilks, 2013), Prezi is a program for presenting information within a hierarchical structure. The user can be led from a general overview on a topic to more detailed information by zooming in the different levels. Additionally, different file types can be included, for example, films, audio and pictures (Krause et al. 2014).

Also many WebQuests have been developed by the Departments of Chemistry Education of Bremen, Frankfurt, and Hildesheim. These WebQuests usually deal with general chemistry (i.e. structure of matter, introduction to the mol, the chemistry of copper), sustainability, and bionics.

Visualisation tools

A project with its main focus on visualisation tools is Ch*i*Le (*Chemie interaktiv Lernen/Learn Chemistry interactively*) which was started by the author of this article in 2003. So far, the main fields of work concentrated on have been organic and electrochemistry. Ch*i*Le (see Figure 3) does not develop full digital learning units; it can be seen as more of a database (Ch*i*Le, 2013). Therefore, the different visualisations, usually 3D models and animations of experiments on molecular level or of reactions mechanisms, can be used in almost any setting in class.

Various studies at secondary schools have been conducted to investigate benefits or dangers of using digital visualisations in class. Animations usually serve as means to foster problem solving (Pietzner, 2007) and to facilitate students' cognitively picturing the atomic level (Pietzner, 2005), particularly when compared with a more traditional way of static, non-interactive visualisations. In addition, the learning climate has, in particular, improved for the girls attending chemistry classes (Pietzner, 2006). An analysis of the learning climate proves that it is possible to investigate the affective aspects related to learning in class. Using digital visualisations, the girls demonstrate more satisfaction; also, the comprehension was raised from the girls' point of view, and it almost reach the level of the boys.

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Chemical and physical properties

Chemical properties are processes containing a change in the composition of a substance. One or several substances (educts) are transformed into one or several different substance(s) (product(s)).

Examples of **chemical properties**:

- iron rusts
- sodium reacts very vehemently with water

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- carbon burns by exposure to air or oxygen

  🎦 - combustion of carbon in oxygen - LAN - 56K Modem -

- salt formation with acids or bases

In contrast to that, physical properties are properties that are not accompanied by a change in the composition of a substance.

Examples of **physical properties**:

- colour
- density
- hardness
- melting point
- boiling point
- solubility in liquids

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Chemical compounds

A chemical compound consists of molecules containing different elements. The elements are in a defined ratio.

Carbon monooxide is a chemical compound, because the carbon monooxide molecules consist of one carbon atom and one oxygen atom each. Ethyl alcohol is a further example of a compound. In contrast to that, oxygen (O_2) is not a compound but a chemical element.

substance	formula of the molecule	number of atoms in the molecule
oxygen	O_2	2 oxygen atoms
carbon monooxide	CO	1 carbon atom 1 oxygen atom
ethyl alcohol	H_5C_2OH	2 carbon atoms 6 hydrogen atoms 1 oxygen atom

In the names of compounds consisting of two elements (binary compounds), the element that is more electropositive (often a metal) is mentioned first. Afterwards, the element that is more electronegative is mentioned with the ending "-id". Greek prefixes indicate the number of atomic species of the compound. However, there are exeptions of this notation system as well as a frequent use of trivial names.

Figure 2. Two screenshots of CHEMnet
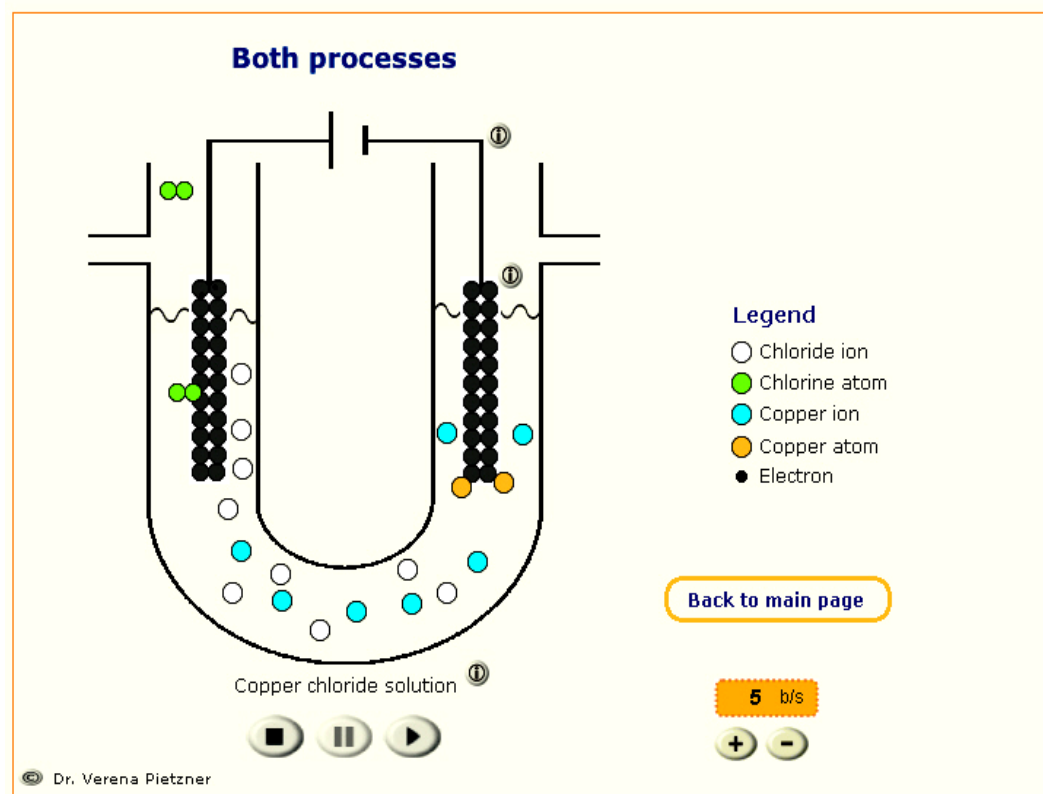
The Electrolysis of Copper Chloride

Figure 3. Screenshot of an animation of ChiLe

In recent years, the work of ChiLe has been extended to include those studying at university level, and ChiLe@Uni came into being. For this project, the materials and research of ChiLe was transferred to include chemistry education at tertiary level. In cooperation with the chemistry educators from Bremen University, the implementation of new teaching methods into the chemistry university curriculum and the practice of the students' media competence by developing their own films dealing with chemical experiments is being investigated.

Ten years before ChiLe was started, the researchers of the University of Erlangen-Nurnberg started to work in the field of computer-based learning. Staring with computer-based experiments (Steiner, Lehnerer, 1992; Steiner, Lutz, 1995), they soon began to focus on Molecular Modelling (see Figure 4 for an example) and how to introduce this technique into chemistry classes (see e.g. Steiner, 1997, 1999, 2001). In order to do this, they frequently used professional software such as Hyperchem and Spartan. The students could learn what molecules 'see' from each other, and learn to predict chemical reactions by working with electron density values.

On the homepage of Steiner (Steiner, 2013), multiple information about possible uses of molecular modelling including teaching materials and general information about the different software are provided.

Data logging

The *AK Computer im Chemieunterricht* (i.e. Working Group for Computers in Chemistry Lessons) was established in the late 1980s. It works on developing suitable interfaces and software for chemistry classes and its members have developed the All-Chem-Misst (i.e. all chemistry measurement device, an interface between a computer and any kind of electrode or scales). Additionally, the group also developed software for the logging and evaluating the data, and learning software (Kappenberg, 2013). Many schools use the device and software developed by Franz Kappenberg, one of the main participants of the AK. Recently, the
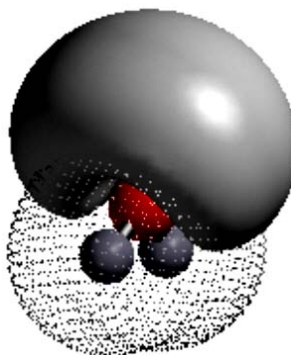
Figure 4. A 3D model of a water molecule showing the free electron pair as well as the van-der-Waals radius of the hydrogen atoms

AK also published an Android App called AK Mini Labor (i.e. AK Mini Lab).

Computer-based collaborative learning

The chemistry educators of the Leibnitz University in Hannover focus on collaborative learning. They do not develop learning material, but focus on the understanding of how computers can help the students to reflect on their work and how to promote collaborative learning (Bell, Urahne, Schanze & Ploetzner, 2010; Urahne, Schanze, Bell, Mansfield & Holmes, 2010). The work began from an investigation of the use of CmapTools, a freeware program used to develop personal concept maps. Schanze and his team investigated the influence of using CmapTools on the learning outcome (Stracke, 2004). This group then became part of the CoReflect project, funded by the EU. The aim of this project was to develop and evaluate tools to enhance computer-based collaborative work. The focus of Schanze's work is still on the use of computers and digital media as tools (Heinrich, Hundertmark & Schanze, 2013; Sieve & Schanze, 2013; Schanze & Sieve, 2013; Schrader & Schanze, 2013).

Currently, the department of chemistry education at Hannover University is investigating the attitude of chemistry teachers towards interactive whiteboards and their work with this tool, and continues to work on mapping software. Recently, they have also begun to work on a digital chemistry textbook (Ulrich & Schanze, 2013).

The activities and projects presented here have different levels. Some researchers have done much developmental work and have published, in German teacher oriented journals, but did not conduct empirical studies. Empirical studies on computer-based learning in chemistry classrooms have been published by Schanze et al., Eilks et al., and Pietzner et al. both domestically and internationally. Additionally, general ideas on teaching and learning with computers, especially reflecting the quality of animations that can be found on the internet, have been published by Eilks et al. (Eilks, Witteck & Pietzner 2009; Eilks, Witteck & Pietzner, 2012). However, to summarise, empirical research into computer-based learning in chemistry education in particular and in science education in general is more an exception than the norm in Germany.

Recent Developments

Despite computer use in chemistry classes seeming to be much less than is deemed desirable, chemistry teachers and educators continue to work on this problem and make much effort to develop materials for teachers as well as investigating computer-based teaching and learning. Recently, digital visualisations for Higher Education have also been developed. In addition, new methods for university teaching are being combined with the integration of digital media such as lecture videos and student response systems.

In addition to the development of computer applications, the teachers themselves have become a focus of investigation. Chemistry educators have started to focus on the teachers' computer related or technological pedagogical content knowledge (TPCK). TPCK focuses on teachers' knowledge of learning and teaching with computers in their respective domain and is therefore closely related to PCK (Mishra & Koehler, 2006). The preliminary results show that professional development for chemistry teachers is crucial for a successful integration of computer-based teaching and learning. However, further studies have to be conducted to obtain more information about the needs of the teachers. The next step will be to develop a computer literacy curriculum for German science teachers.

The third line of development is to investigate the possibilities of mobile devices like Tablet-PCs and Smartphone. Some groups have started conducting research to discover what can be done with these devices in chemistry classes. Physics educators have already made considerable progress in this area because Smartphones have some very useful sensors for physics education. For example, students can measure temperature, sound volume and can make videos of a movement and evaluate them using video apps.

For chemistry education, documentation tasks such as a picture series of an experiment could be useful tools. On the other hand, Apps for 3D molecular models such as Jmol Android have the potential to be useful tools in chemistry class. However, as is the case with computers, the question of equipment, platform (Android, Windows, iOS) and the availability of Apps will be important for the sustainable use of mobile devices.

CONCLUSION

There are some fields, for example, physical chemistry (electrochemistry, chemical equilibrium) and organic chemistry (organic reaction mechanisms) that researchers investigate, in Germany as well as on international level, but many important topics in chemistry education have, as yet, been ignored and therefore need to be elaborated. Some examples for topics that would profit from the implementation of computer-based learning phases are the structure of matter, chemical bonding or structure-related properties.

Therefore, researchers should renew their efforts and continue the empirical research and, in addition, continue further developments for teaching chemistry.

Team work, which also includes teacher input, is particularly important in order to develop good practice examples. With this, it might be assured that the new concepts address day-to-day teaching at school and that theses could have lasting effects. This team work could be structured following the Design Based Research (The Design-Based Research Collective, 2003) approach and/or the Concept of Action Research (Brydon-Miller, Greenwood & Maguire, 2003). These good practice examples could then be the focus of professional development courses and in teacher oriented journals. This would help to support teachers and encourage them to make their own effort to include computers in their teaching.

Looking at the different school types in Germany it can be seen that most research has, so far, been focused on grammar schools. At an international level, most of the research is done at High Schools or Colleges. For other school types, much less research has been conducted. However, every school type has their own special needs and goals, and therefore researchers should include multiple school types in their research. This may lead to a more elaborate view of computer-based teaching and learning at school, covering elementary school as well as the different secondary school types.

Regarding the teachers, computer-based teaching seems to be a topic which has been greatly neglected. Therefore, chemistry educators should incorporate this topic in the University curriculum. At university, teacher trainees should learn about basic concepts and strategies of how to implement computer-based learning in chemistry classes and how to foster the students' computer literacy. Additionally, the study programme should enable the pre-service teachers to develop their own computer literacy during their professional careers, bearing in mind that for a proper professional development it is important to attend professional development courses and workshops.

Finally, chemistry educators and other stakeholders in the field of professional development for chemistry teachers are invited to develop programmes that address the teachers' needs on multiple levels. Teachers that want to start implementing computer-based teaching and learning in their chemistry lessons need to be supported as well as teachers that need advanced courses for special computer applications.

Doing research and development that addresses all levels of teaching could finally manage to make the use of computers in chemistry classes the norm rather than the exception.

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