Information and Communications Technology in Chemistry Education

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This article looks at the possibilities of Information and communications technology (ICT), which is also central in supporting teaching and learning of chemistry. It is also vital in promoting sustainable development. ICT is a general concept, under which all different media and technologies can be placed, which can be used as support in data processing. The topic is quite broad and needs demarcation. The theory of blended learning can be used here, which is one of ICT's theory frames that models the possibilities of using them in teaching (see Pernaa & Aksela, 2013). In order to support pondering, examples and recommendations of software are presented, which the teachers' can exploit in teaching. This article is partly based on Johannes Pernaa's doctoral dissertation, which was completed in 2011 (Pernaa, 2011), where it was researched, how ICT-based chemistry learning environments are developed based on research. The developing of learning environments based on research is an important standpoint in the topic, which is why we look at it more closely at the end of this article.

The general opportunities of Information and communications technology

Through literature on blended learning, the opportunities of ICT can be for example divided into four categories:

1. ICT makes dynamic and interactive visualization possible for phenomena and processes e.g. through animations and simulations
2. ICT creates new opportunities in carrying out social interaction
3. ICT releases teaching and learning from time and place, if necessary
4. ICT makes it possible for data acquisition, processing of data and sharing of data to be more effective. It is possible to get hands on information quickly and exhaustively everywhere. This changes a person's idea of know-how. (Osguthorpe & Graham, 2003)

For example through electrical learning environments functioning in the internet browser, students are able to get their hands on the learning material from anywhere at any time. The internet is the way to a limitless information stockroom and makes a complex, communal building of information possible. Information can be built, shared and criticized e.g. between a student's own class in a discussion forum in the electrical learning environment and at the same time on a global level through social media. Global network-based reserve of information and communication channels also promote sustainable development, because of information resources and dialogical connections, traveling is not necessary.

Raised on the basis of the theory of blended learning, the opportunities of ICT are general, and they apply to all observations on learning, but the 1st category is especially interesting from the point of view of visualization of information in chemistry. Therefore the rest of the article focuses on looking, with the help of examples, at what kinds of opportunities ICT offers for visualization of information in chemistry.

Elucidation of chemistry with the help of Information and communications technology

One of the biggest leading principles in research on chemistry teaching is the fact that chemistry is a difficult subject partly because of the fact that same piece of information can be considered on many different levels at the same time. In chemistry, information can be studied on the macroscopic (visible), submicroscopic (invisible) and on the symbolic level (structural formula).

These three levels are generally called as the three levels of chemistry. For a professional (a chemist, a teacher), it is quite easy to think of the visible world in structural formulas and dynamic processes happening in the microscopic level, but for a novice (a student, a pupil) modelling is difficult. Therefore, we need ways in which to visualize information in different levels and to concretize connections between them. ICT offers the necessary visualization tools for this challenge. The most used tools, used to visualize different levels, are animations, simulations, videos and molecular modelling in chemistry. (Johnstone, 1993; Kozma & Russell, 2005; Pernaa & Aksela, 2013)

Animation is a set of pictures with which it is possible to create moving pictures. Animations are quite suitable in describing processes and phenomena in chemistry. They are pedagogically a versatile type of media. A teacher can use animation in presenting information, but it is also possible to make the students create animation themselves. Creating an animation is a very active process, where higher order thinking skills such as analysis, evaluation and recreation, need to be exploited during the planning phase of the animation (see Michalchik et al., 2008). For example ChemSense is a suitable animation software for this purpose. ChemSense can be downloaded here: www.chemsense.sri.com.

Videos are digital videos just like animation, but they differ from each other from the point of view of chemical information. In animation in chemistry, the microscopic level is studied, whereas on the videos it is possible to present phenomena on the macroscopic level. With the help of video processing, it is possible to edit video recordings, which then connects videos on the macro level and animations on the micro level. Video documents can be connected together in levels so that in one video presentation, several videos and animations can be studied at the same time. Videos are exploited quite much as support during practical work. They support e.g. the safety of laboratory work and save time, if necessary. With the help of videos, we can be introduced beforehand to inquiry-based processes, possible sources of error, parts that need accuracy and how to present dangerous tests in a safe way (Laroche et al. 2003). With current technology, it is easy to make videos, because everyone has a smart phone with which to film the videos.

Molecular modelling means modelling of individual molecules or small static systems, whereas **simulations** have the opportunity to deal with larger systems. Simulations differ from molecular modelling also, because dynamic processes are examined there. In molecular modelling, the user has an active role and the software gives freedom to the user to build, calculate and visualize the system in the way they want to. In simulations, the rights of the users are more limited. Often the user does not perform the calculation, since the simulation is based on data that has been calculated beforehand. (Kozma & Russell, 2005) The opportunities of these two ICT tools can be tried individually quite easily with free network applications. For example Edumol (www.edumol.fi) (Pernaa, 2015) is an open and browser-based environment for the modelling and visualization of molecules. Chemistry simulations of high levels are available in for example phet.colorado.edu.

Molecular modelling and simulations make the following possible: the stopping of reactions, the calculation of energies and the visualization of the vibrations of molecules. With the help of animations, we can present how chemical reactions progress. The modelling and visualization of phenomena helps students to evaluate and test internal models. With the help of ICT, we can bring dynamics into phenomena. With the help of pictures in printed books, it is quite difficult for students to model the moving and vibrant nature of molecules. (see e.g. Tasker & Dalton, 2006; Russell & Kozma, 2005; Rapp, 2005)

Building logical structures of concepts

Up to this point, it has been considered in the article, how the three levels of chemistry can be visualized using different ICT tools. Next, we are to ponder how connections between different levels can be concretized with the help of ICT. Concept maps are ideal in this kind of an assignment for example (Novak & Cañas, 2008). Concept map is a tool for outlining information, where concepts are connected to each other with a linking word that shows their relation to each other. Concept maps can be made by hand, but it is easy to include different pieces of information such as pictures, sound, videos, animations, links and other documents to electrical concept maps. In the following picture (Figure1), there is a simple concept map on isomerism, where an example on a submicroscopic level is presented of all the isomerism categories.

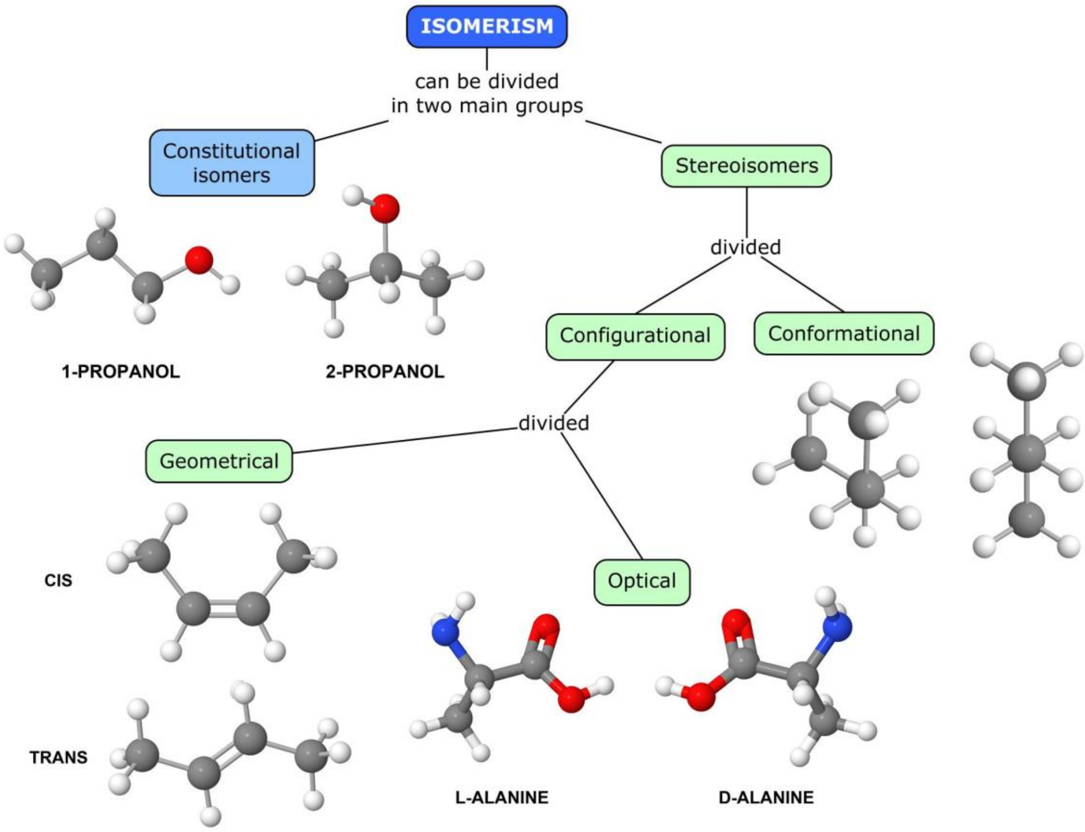

Figure 1. A simple concept map of isomerism. This map has been made with the CmapTools software.

Concept maps have been developed to be tools of thinking. The building of concept maps visualizes a student's information structure of a topic and then its presentation, criticizing and further development is easier. Also, making concept maps activates higher order thinking skills, diversely (Pernaa & Aksela, 2010).

Research-based developing of learning environments based on Information and communications technology

The development of ICT-based as well as other learning environments is recommended to be carried out systematically by exploiting a research method suitable for developing learning environments – design-based research. Research-based development is important, because then development can be controlled, and organizations as well as individuals taking part in development can learn as much as possible of the process. (Pernaa, 2013)

Design-based research is a research method, where development and researching are connected in a cyclic process that consists of theoretical and inquiry-based phases. With the design-based research, it is possible to get answers to the three following questions: i) how the design process will proceed, ii) what needs and opportunities the design will address, and iii) what form the resulting design will take? The answering of these three questions divides the development decisions in this development research into three categories: 1) design procedure, 2) problem analysis and, 3) design solution. (Edelson, 2002)

1. In the development decisions of the **design procedure category**, the people and the work processes needed in the design, preparation, carrying out and in the evaluation and further development of the research process and the design solution of the project.
2. In the **problem analysis** category, the challenges and needs of a design-based research are figured out and the aims are described. Problem analysis can be theoretical or empirical. It can consist of for example analysis on already existing learning environments and textbooks or of a questionnaire on teachers' needs.
3. The **design solution** category is the developers' solution to opportunities and challenges that emerged during problem analysis. Design solution is a learning environment that has been developed in a project. It develops interactively, when the cycles of the research process go forward and the developers' information immerses. (Edelson, 2002)

Usually the development research cycle consists of the following four phases: 1) needs analysis, 2) the development phase, 3) practical testing and evaluation and 4) further development. Based on aims, time and resources, there are one or more cycles. Development always begins with a problem, which is based on theory or practice. In needs analysis, this problem is explained, the challenges and possibilities in development are analyzed and a development plan is created. In the development phase, a practical solution is built according to the development needs defined in the needs analysis. The learning environment developed after the development phase is tested in a practical teaching situation. The aim of development can be for example a whole course or some smaller activity inside a larger course entity. At the end of practical testing, the design solution and the success of the development process itself is evaluated and if necessary, a further development plan is made. It is important for evaluation to focus on both the solution as well as the process, so that we could learn about development in a diverse way. This way it is possible to develop better and in a more accurate way in future. (Pernaa, 2011; Pernaa, 2013)

Research-based development should not be thought of as such that it would take too much trouble. It is no use to do work, where different stages, results and contribution are forgotten gradually. Own work should be appreciated by documenting it. The process can always be carried out quite easily. For example the teachers' coffee room discussions and textbook analyses in the own school's library, can act as a problem analysis. Evaluation can be carried out with a simple student questionnaire. Here, it is just important to write down the observations and to make notes of the process as well as to draw justified conclusions. The completed work and conclusions can be summarized into a blog entry and it can be published into free discussion for the colleagues or for the person itself. This is how the profession goes forward and a person's own knowledge increases. Developing oneself is important in a quickly developing ICT environment. Design-based research gives this an excellent tool.

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