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DIDACTIC ANALYSIS OF THE WEB ACID-BASE TITRATION SIMULATIONS APPLIED IN PRE-GRADUATE CHEMISTRY TEACHERS EDUCATION

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Abstract. *The wide development of the information and communication technologies provides conditions for using various digital learning objects in education. In Chemistry learning and teaching computer simulations are used for increasing clearness in Chemistry lessons and for supporting experimental activities in laboratory work. For this analysis the topic of acid-base titration was chosen. The research sample included educational simulations of acid-base titration available free on the Internet. In total 35 educational simulations of acid-base titration were found and used for didactic analysis with following research questions: What can be learned from educational simulations of acid-base titration? and How can didactic analysis of different kinds of simulation help to teacher and learner? In the research results of didactic analysis of 35 examples of acid-base titration simulators are presented. Resulting from the analysis we find three different types of educational simulations of acid-base titration with a specific use in Chemistry lessons: (1) simulations of experiments; (2) generators of titration curves according to the user's choice; (3) presentations of one titration. The summary of all analysed simulations and proposals of their educational applications is available from the web site http://titrace.wz.cz.*
Key words: *acid-base titration, chemistry instruction, didactic analysis, educational simulation.*

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Introduction

The wide development of the information and communication technologies supported by increasing number of interactive boards in Czech secondary schools provide conditions to applied Comenius´ principle of clear explanations in chemistry teaching, when not only demonstrative and pupils´ experiments can be used but their computer models and simulations as well.

Modelling is a traditionally applied theoretical method in research activities. Malík (1989, p. 1) Describes it as *"... a situation, when we research part of the real world, a more suitable for us than another one the features of which can be applied to the original part."* The main objective of the modelling method is to create models, verify their correctness and run experiment's results of which can be applied to the researched reality. The original and the model are two systems similar each other to some extent. This method does not firmly relate to using computers but as we can see it is valuable.

Simulations are a special type of modelling when time characteristics of phenomena are presented. *"Generally, simulations and animations is such a method which replaces a researched dynamic system by the model presenting the modelled system in operation or can be used for running experiments."* (Bílek, Nodzyńska, Paśko & Kmeťová, 2007, p. 13). The simulator works in the real time ***t*** and simulated time ***t´*** situations ***s*** in real system and ***s´*** in simulated system appear which are similar to considerable extent.

Educational simulations are not clearly scientific ones; they are adjusted to the learners´ cognitive level. It means that redun-

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dant professional information is reduced, while the didactic support forming the learner's process of cognition is added. Computer educational simulations are classified as digital educational objects and can be defined as: *"computer-generated dynamic models that present theoretical or simplified models of real-world components, phenomena, or processes. They can include animations, visualizations, and interactive laboratory experiences"*(Bell & Smetana, 2008). They serve as sources of information, simulators of experimental activities and tools for solving problem tasks or testing hypotheses within the instruction. (Bell & Smetana, 2008; Beaufils & Richoux, 2003) *"While interacting with simulations, learners are engaged in processes of scientific reasoning, such as problem definition, hypothesis generation, experimentation, observation, and data interpretation."* (Plass, Milne, Homer, Schwartz, Hayward, Jordan, Verkuilen & Barrientos, 2012) The process of instruction which uses the models is called Model Based Learning in English-speaking countries and is understood a constructive process focusing on learner´s activities, e.g. re-constructing, interpreting, experimenting, predicting, managing, gaming, creating, evaluating (Frischherz & Schönborn, 2004) so that the final mental model of the studied phenomena was created (Gobert & Buckley, 2000).

The educational simulations reduce real phenomena to reach the predefined learning objectives, support the process of forming images about the reality in learner's mind and continuously reflect the researched reality. Following three steps were proposed by Frischherz and Schönborn (2004) towards designing didactically efficient simulations: (1) scientific analysis of the problem and designing the conceptual model; (2) the conceptual model reduction in relation to learning objectives, adjusting to the learner's cognitive level and creating a didactic model; (3) computer processing and creating a design model. Two substantially different layers are required for the computer processing of a simulation (Le Maréchal & Bécu-Robinault, 2006). Layer 1 is hidden from users and covers algorithms processed by CPU. Layer 2 ensures the process of displaying on the screen via various semiotic registers, which relates to calculations in layer 1. Such a computer simulation enables to create a mental model in learner's consciousness which is a reconstruction of the conceptual model of the researched problem. The adequacy of the mental model undoubtedly depends on the quality of the educational simulation, mainly on the approach how it is applied. Frischherz and Schönborn (2004) also mention the quality criteria for animations and simulations as learning objects which provide the added value to the process of instruction. They define following quality criteria: *Scientific standards, Content selection and reduction, Learning activities, Media types Didactic context, Visualization, Usability, Aesthetic quality.*

The presented quality criteria relate to the demand for analysis and evaluation of free educational simulations created by authors who more or less keep the didactic principles and satisfactory professional level of the modelled phenomena.

New questions of pedagogy and subject didactic research have appeared relating to the implementation of these tools, mainly focusing on efficiency, results of instruction, support of constructing and fixing new knowledge, support of experimental activities or comparison of the importance of real and virtual experiment in science education. Many academic workplaces worldwide deal with these questions. The most important researchers in this field are e.g. Plass (2009; 2012), Greenbowe (2008), Smith (2010) and Bell (2007) in the USA, as well as Le Maréchal (2006), Lamanauskas (2011), Josephsen (2006), Winberg (2007) and Bolton (2008), Burewicz and Miranowicz (2006), Pinter (2012), Turčáni and Magdin (2012) in Europe and e.g. Bílek (2011) or Šedivý (2013) in the Czech Republic.

The impact of steadily implemented researches has been reflected in approaching to these didactic means. The didactically highly-developed educational simulations have been saved online, e.g. on the web pages of PhET Simulations (University of Colorado, 2011) or Chemical Education (Greenbowe, 2008). The educational computer simulations are also included in interactive appendices of natural science textbooks, e.g. the project Microméga run by prof. J. F. Le Maréchal from L'École Normale Supérieure de Lyon and his team (Le Maréchal & Bécu-Robinault, 2006). Thus they have become the didactic means systematically implemented in the Natural science curricula (Rutten, van Joolingen & van der Veen, 2012).

In the Czech Republic the systemic process of designing learning simulations has not started; teachers mostly use simulations available on the Internet. This approach may involve huge risk, e.g. matter-of-fact mistakes in the model of a real situation may appear, the simulation does not reflect students´ level of knowledge, it does not closely relate to the topic taught, unsuitable semiotic registers for displaying phenomena are used etc. Consequently, the learning content can be understood incorrectly from learner´s point of view. That is why searching for and proposing new approaches to analysing and evaluating their quality is highly appreciated. Having been defined, these processes should be implemented in the training programmes of pre-graduate chemistry students.

The main purpose of this work is to apply the method of didactic analysis, which is widely used for evaluation teaching means, e.g. textbooks, on a unified set of computer learning simulations, freely accessible on the Internet, and show a possible way of critical evaluation of such a means before included in the process of instruction.

Within the research from the point of learning content we analysed acid-base titrations, which is the topic where the theoretical calculations (theory of acids and bases, chemical equilibrium) and practical experimental activities are joined. Le Maréchal and Bécu-Robinault (2006) emphasize simulations play an important role in mediating the micro-world and theoretical models. In the process of acid-base titration students manipulate with the titration apparatus and solutions, observe changes in colour of acid-base indicator or pH-value on the pH-meter. When interpreting the results, they should be able to record the equation of the chemical reaction, calculate the concentration, draw titration curves. These are tasks not met in laboratory practice. The well-designed acid-base titration simulations enable students to run virtual experiments, follow the course of the titration curve and visualization of the course of reaction on the molecular level (dynamic equilibrium of the reaction). This multi-register display might help students understand the context of single phenomena.

Thus the main research aim is to detect the didactic support and quality of learning simulations of acid-base titrations via method of didactic analysis. Main research questions are defined as follows: "What can be learned from educational simulation of acid-base titration?" and "How can didactic analysis of different kinds of simulation help to teacher and learner?"

Methodology of Research

General Background of Research

Didactic analysis traditionally deals with three main questions: What should be learned (learning goals)? What should be the material used to reach learning goals (learning content)? How should this learning content be learned (learning and teaching methods)? (Bopp, 2006) This concept was applied by Bopp (2006) in analysis of robust computer learning games.

The research focuses on learning simulations with specific learning objective, which was the reason we decided to analyse them in detail from following three criteria:

1. Clearness of the simulation.
2. Process of controlling the learner's cognitive activity.
3. Interactivity of the simulation.

A form was designed for collecting data where the discovered qualities were recorded in the form of bi-polar analysis (yes/no) in single items of each simulation.

From the point of clearness the static or dynamic graphic information was evaluated, whether and how the titration apparatus, pH meter, changes of colour and functional areas of acid-base indicators, titration curve, equivalence point, chemical equation of the reaction and its animation on the molecular level are presented.

In methodology of learner's control the analysis focused on discovering whether the application sets the task before titration, or asks questions after the titration, whether the feedback is provided, learner's performance evaluated and summary or conclusion are provided.

From the point of interactivity it was evaluated, whether and how the titration apparatus is handled, how the researched and standard solution and equivalence point indication are selected, how the titration is made and whether solutions can be included.

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Research Sample

The subject of didactic analysis was "online learning simulations of acid-base titrations", which are peculiar computer programmes based on acid-base titration simulations, free-available from the Internet. The open-accessed acid-base titration simulations were included in the sample, i.e. 35 educational simulations. List of links of the analysed simulations is in appendix, they are also available from the website http://titrace.wz.cz.

The research sample was set by the Google Web and Google Images search engines. First, 10 key words were set (Acid-base titration, Simulation, Acid-base titration, Animation of acid-base titration, Titration curve, Generator of titration curves, Volumetric analysis, Neutralization, Neutralization titration, Acid-base indicators, Acids and bases) and translated into 15 foreign languages (English, Chinese, Danish, Finnish, French, Dutch, Italian, Japan, German, Norwegian, Polish, Portugal, Russian, Spanish, Swedish) using Google Browser. The search process ran from June 2010 to August 2011.

The researched simulations were designed in 1996 – 2009, the data were not found with 9 simulations. Authors were identified with 27 simulations, 22 of them are academic staff. Simulations communicate in various foreign languages, which are displayed in diagram (Figure 1) and are made in two formats: Java (N = 13) and Flash (N = 18). Following diagram (Figure 2) reflects the relation between the format and year when the simulation was designed. It can be seen simulations designed before 2000 are in Java format, while most of those designed later are in Flash format what confirms main changes in programming background of Internet application.

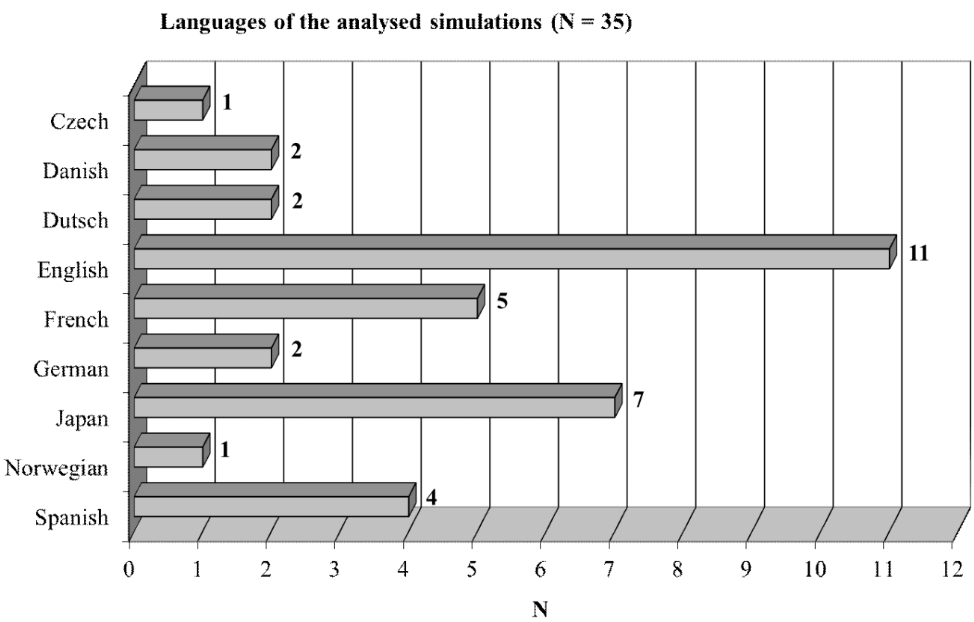

Figure 1: **Languages of the analysed simulations.**

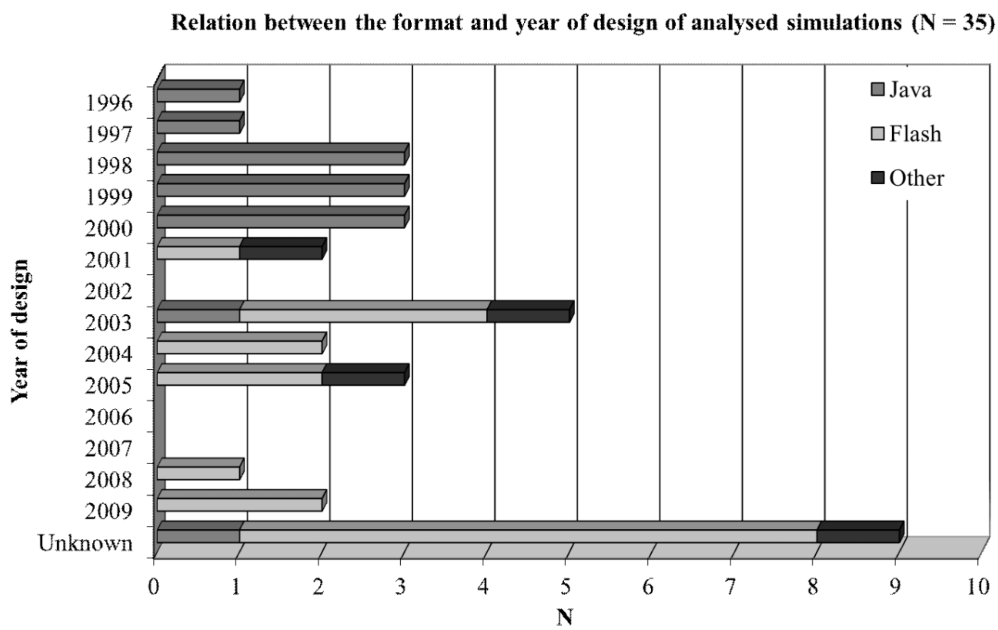

Figure 2: Relation between the format and year of design.

Results of Research

The findings of clearness' analysis are presented in following diagram (Figure 3).

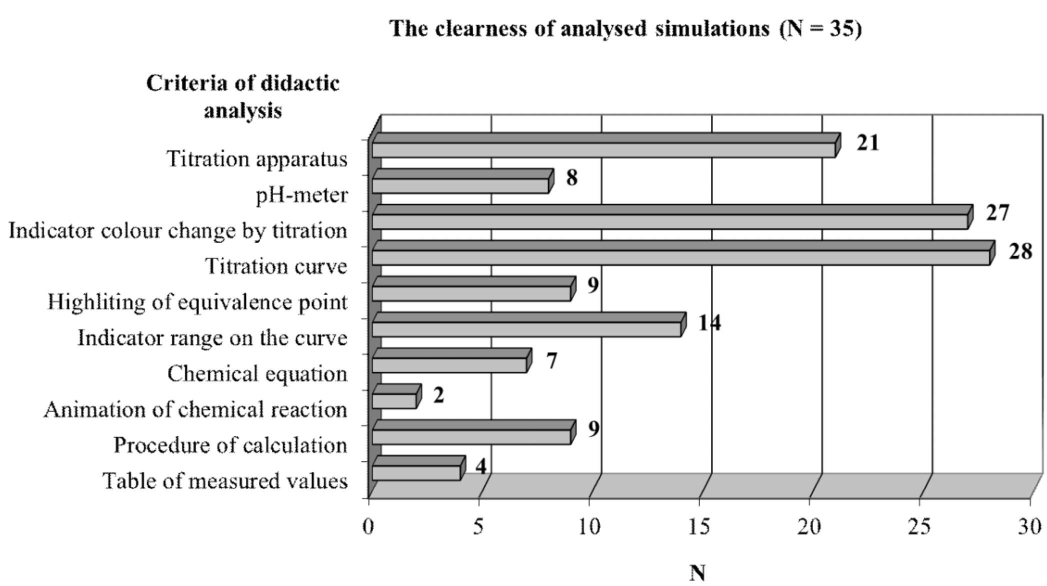

Figure 3: The clearness of analysed simulations.

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The titration apparatus is displayed in 21 simulations as an interactive model (N = 6), a dynamic model (N = 11) and a static schema (N = 4). The titration curve is displayed in 28 simulations. It is drawn successively in relation to the added volume of the standard solution (N = 11) or the curve appears after pressing the key (N = 17). The equivalence point is highlighted on the titration curve in 9 simulations; only one simulation shows how to define it. Work with the acid-base indicator is provided in 27 simulations, often its coloured course during the titration is displayed (N = 22), and its indicator range is displayed on the titration curve background in colours (N = 13) or by straight lines (N = 1). In 9 simulations the user can watch the colour changes or indicator ranges of acid-base indicators before the indicator is selected. An alternative way of running the titration using the pH-meter is provided in 8 simulations, the user can operate with an interactive model of pH-meter (N = 2), while in the other simulations the pH-meter model is firmly connected to the apparatus. The chemical equation of reaction is displayed in 7 simulations. Visualization of the reaction by animation on the molecular level is shown in 2 simulations. The process of calculation is available in 9 simulations and the table of measured values can be found in 4 simulations.

Findings of analysis in the field of controlling learner's cognitive activities are displayed in the diagram below (Figure 4).

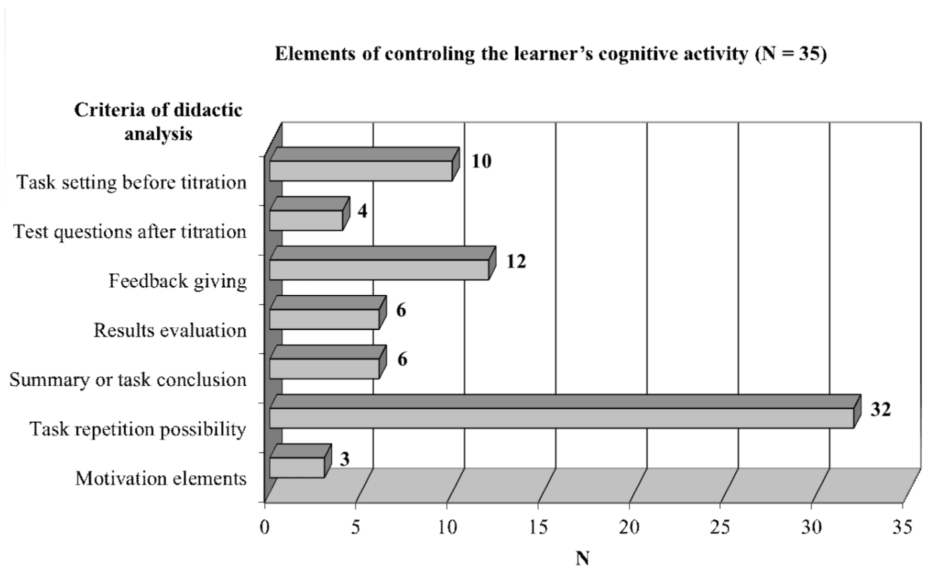

Figure 4: Elements of controlling learner's cognitive activity in analysed simulations.

The task is defined in 14 simulations. The task is set at the beginning and the user solves it as doing the virtual laboratory experiment (N = 10) or the control questions are asked after the titration (N = 4). The feedback is provided in 12 simulations. It informs whether the solution is correct (N = 9) or adds the correct solution (N = 3). If the solution is not correct, it informs about the fact only (N = 3), provides the correct solution (N = 2) or enables to submit another solution (N = 7). Evaluation of learner's performance is provided in 6 simulations as well as the summary or conclusions of the titration. Totally 32 simulations enable to repeat the same titration again. Motivation elements are mostly missing, they were included in 3 simulations only.

The results of interactivity analysis are presented in diagram below (Figure 5).

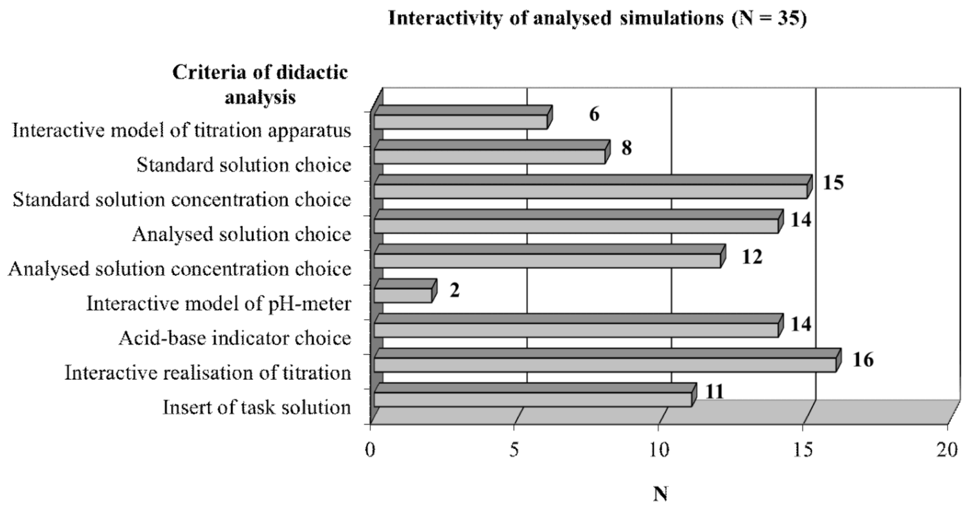

Figure 5: Interactivity of analysed simulations.

As mentioned above, the interactive titration apparatus model is provided in 6 simulations and the interactive model of pH-meter is included in 2 simulations. These models mostly enable to manipulate with the burette cock, in 3 simulations it is possible to build the titration apparatus themselves and in 1 simulation the user can take the aids, which are required for the construction, from the virtual store and start work. The user can influence the volume of the added standard solution from burette (N = 16). This function is under the key control with several options, e.g. the flow speed setting and burette cock control, or inserting of added volume by number on keyboard. The user can choose the standard solution (N = 8) and determine its concentration (N = 15). The user can choose also the analysed solution (N = 14) and determine its concentration (N = 12). In 11 simulations the analysed solution is set with unknown concentration which must be calculated by the user. In 14 applications the user can choose the acid-base indicator for the equivalence point of the given titration. The user can run virtual experiment in 16 simulations. In 11 applications the user can insert their solutions of measurement by the way of open type response (N = 8) or the multiple choice one (N = 3).

Discussion

In the above described analysis 35 learning simulations of acid-base titrations were analysed from three criteria: clearness of the simulation, process of controlling the learner's cognitive activity and interactivity of the simulation. Within the process each criterion was structured in several specific sub-criteria.

From the point of clearness the analysed applications we identified three categories: (1) simulations presenting the process of titration (virtual experiment), (2) simulations presenting the course of the titration curve and acid-base indicators ranges and (3) simulations combining both categories. The results of didactic analysis showed in this part that the titration apparatus, titration curve and colour change of acid-base indicators during the titration were mostly displayed. On the other hand, the possibility to connect the pH meter, highlight the equivalence point on the titration curve, display the equation of the chemical reaction, the animation on the molecular level, the table of measured values and the calculating procedure were missing.

From the point of controlling learner's cognitive activities we structured the analysed simulations on two categories: (1) methodically advanced, well-developed learning objects simulating task solu-

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tions, the procedure and providing feedback and (2) methodologically incorrectly-developed learning objects, i.e. generators of titration curves which need some external support for guiding users' learning process, or animations which serve as a pictorial didactic means and illustrate the learning hypertext. The quality of simulations is of low level which can be caused by the fact these functions are difficult to be programmed.

From the point of interactivity the analysed simulations we structured in two groups: (1) simulations with high level of interactivity, i.e. those which enable the user to choose matters, operate objects, insert solutions etc., and (2) simulations with low level of interactivity, i.e. those controlled by one key, providing the slide show only etc.

As it was mentioned in introduction and as we can compare with provided research studies, educational simulations can serve as sources of information, simulators of experimental activities and tools for solving problem tasks or testing hypotheses within the instruction (Bell & Smetana, 2008; Beaufils & Richoux, 2003). Corresponding with this and resulting from the analysis the analysed simulations of acid-base titration can be finally categorized as follows: (1) simulations of experiments, (2) generators of titration curves according to the user's choice and (3) presentation of one titration. Each type of application needs specific approach to instructional goals formulation, their realisation and evaluation. From this point of view we can formulate next conclusions:

"Simulations of experiments" are applications of high visualisation level, well-developed learning activity management and wide interactivity. They are learning objects which enable running virtual experiments and work with collected data. Simulation of experiments can serve learners as trainers of laboratory activities, virtual experiment or a means of independent practising. The applications set the task, follow the process of titration to some extent and provide feedback.

"Generators of titration curves" according to the user's choice are applications focused on drawing titration curves. They do not provide well-designed student´s learning management but their clearness and interactivity is on acceptable level. Student´s work is externally managed, e.g. by the work sheet or teacher´s instructions. These learning objects might be used in problem instruction or structured ICT-supported inquiry-based activities. Generators of titration curves can be used in the explanatory phase of the lesson or help students in task solving set by teacher. The titration curve displays the relation of two values, the pH-value and volume of the added standard solution in the model of the chemical process. In our previous work (Bílek, 2001, p. 38) it is stated *"graphs are the illustrative sign models, but the picture does not relate to the presented process and requires the direct necessary participation in mind activity which provides the related links. The picture - graph itself is of material character but the adequate transformations between graph / science phenomenon cannot run without related mind operations."* The successful transformation depends on the level of formal thinking, which is why it is difficult for learners. The systematic and coherent work with generators can help understand the relation between the titration process and titration curve.

"Presentation of one titration" are applications providing dynamic didactic images, they are clear, well-designed from the methodological point of view but their information basis is limited to one concrete case of acid-base titration. Presentations support the process of improving quality, effectiveness and clearness of explanations. They can illustrate the term of the titration curve and its course, indicator range and colour change of acid-base indicator and the course of the acid-base titration. As Maňák and Švec (2003, p. 85) emphasize "*intensive work with picture materials, which on the higher level reflect the reality more and more mediately in the form of schemas and symbols, influences (instead of others) the way of thinking which thus becomes the supportive and jumping-off board for abstractive thinking procedures."* To follow the dynamic schemas can in this case enable learners the process of unclear, non-illustrative conceptual comprehension of the presented phenomenon.

In correspondence with Le Maréchal and Bécu-Robinault (2006) it is said that simulations of chemical phenomena may play an important role in mediating the micro-world and theoretic models. On the other hand, results of didactic analysis of the set of acid-base reactions simulations proved that many authors of pedagogical scenarios did not fully use the possibilities provided by ICT means; e.g. the chemical reaction in the form of equation was recorded seven times and visualization of the reaction on microscopic level in two cases out of all analysed applications.

Conclusions

Didactic analysis of learning simulations (in described study it means acid-base titrations) accessible from the Internet is an important part of chemistry teachers pedagogical content knowledge. It was detected these applications covered three partial topics:

- algorithm of the titration course, i.e. mastering the titration apparatus, dripping the titration solution and monitoring changes in colour of the acid-base indicator;
- course of titration curve, i.e. the form of curve depending on the used solutions, defining the equivalence point and titration solution consumption;
- concentration calculation of the researched solution.

With the analysed learning simulations differences in the level of model and presented design, in general clearness, learning activities management and rate of interactivity were identified. The analysed simulations were divided in three categories; each category had specific features which can be included in teaching practice and teachers´ training. However, all applications should be used as means of attracting learners´ attention, clearness of explanations the learning content and trainers for practising and fixing knowledge and skills. In no case they can be understood as equal compensation of the real experiment.

Learning simulations accessible from the Internet are of different quality and were designed with focus on a certain learning objective, level of education and specialization. That is why each simulation does not correspond to learning objectives of various schools. Before they are applied in pedagogical practice they should be analysed and their adequacy to learners´ cognitive level and learning objective considered. The didactic analysis is an approach of their evaluation. This process is similar to the one of choosing the textbook, educational film or didactic picture.

First, educational objectives should be set which are expected to be reached with the help of learning simulation; second, the learning simulation should be analysed and evaluated whether it meets the above defined learning objectives. Within the innovations in pre-graduate teacher preparation the ICT implementation and electronic learning programmes for outlining the instruction have steadily started. However, this process is part of the whole field. The pre-graduate teacher should be able to use these means efficiently and to acquire processes of critical evaluation of learning applications, which, as clearly seen from the above mentioned, may provide different quality of processing and meaningful use.

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Appendix. List of links to the analysed applications.

N.	URL of simulation
1	http://www.plan-k.dk/flash/interaktivlaering/OpgaverVejledninger/SimpelTitreringAfSyre/flash.html
2	http://www.plan-k.dk/flash/interaktivlaering/OpgaverVejledninger/TitreringAfSyre/flash.html
3	http://users.skynet.be/eddy/titratie.swf
4	http://chemmac1.usc.edu/bruno/java/Titrate.html
5	http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/stoichiometry/acid_base.html
6	http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/stoichiometry/a_b_phtitr.html
7	http://mhchem.org/221/chemland/titration_plugin.html
8	http://groups.uni-paderborn.de/cc/lehrveranstaltungen/_aac/prakt/titrat/titrat.html
9	http://quim.iqi.etsii.upm.es/didacticaquimica/audiovisuales/valoracion.html

N.	URL of simulation
10	http://www.avogadro.co.uk/miscellany/titration/titreset.htm
11	http://www.deciencias.net/simulaciones/quimica/reacciones/neutralizacion.htm
12	http://www.deciencias.net/simulaciones/quimica/reacciones/neutralizacion.htm
13	http://mml.gyldendal.no/flytweb/default.ashx?folder=11164
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