Problems of Education in the 21st Century, ISSN 1822-7864 **VOLUME 37, 2011**

INFORMATION & COMMUNICATION TECHNOLOGY IN NATURAL SCIENCE EDUCATION – 2011

Scientific Methodical Center „Scientia Educologica", Lithuania,
The Associated Member of Lithuanian Scientific Society, The Association of Lithuanian Serials, ESHS (European Society for the History of Science) and ICASE (International Council of Associations for Science Education)

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IN THE 21st CENTURY
Volume 37, 2011

VISUAL TOOLS IN TEACHING LEARNING SEQUENCES FOR SCIENCE EDUCATION

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Abstract

The accelerated development of information and communication technologies followed by several studies in the cognitive theory area, have promoted the use and the construction of many visual tools (3D concrete models, statics or dynamics virtual 2D and 3D images, simulations, animations, interactive software, etc) that have been available to educators. With this research it was aimed to investigate how in-service teachers (n=14) enrolled in a teachers' training course of 40h, understand the nature and the role of visualizations in science teaching as well as the impact of this training. It was also discussed the nature and role of models in science. During the training teachers were invited to build in group teaching learning sequences (TLS) about some science content using visualizations. At the beginning a questionnaire to identify some previous conceptions on this issue have been applied and analyzed. On a later stage it was analyzed the TLS made by them and the audiovisual record of their oral communications to the class. It was also analyzed the final semi-structured interview with these teachers' groups. As main results we highlight a development of the knowledge about these tools, especially on the impact of the visual language on apprenticeship and on the notion of scientific model. We could also observe a change on the reasons and criteria to use these tools. According to the findings it can be said that this training has expanded the teachers' initial notion of models and the theoretical background that support the use of this visual resources which was reflected on theirs TLS.
Key words: *teacher education, visualization, visual tools.*

Introduction

The use of models and visualizations in science and science education, especially in chemistry, has grown up during the last decade. Chemistry involves the interpretation of matter observables changes (e. g. colour changes or gas release) on the macroscopic level in terms of imperceptive changes on the submicroscopic level. These changes are represented in a symbolic and abstract way using symbols, equations, graphics, etc. With the purpose of making these representations accessible to the students, teachers are using visualizations more frequently. Progressively educators began to recognize the value of the visual component on the chemical knowledge, which was until then, only attributed to the verbal and mathematical language; nevertheless the pictorial chemistry language is by itself a higher structured language

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(Ege, 1994). With Jonhstone (1991) the chemical knowledge was divided in *three levels* of representation (submicroscopic, macroscopic and symbolic). For a student immersed in the macroscopic world, the reality, it becomes very difficult for him to understand the concepts and the processes located at the submicroscopic level and represented in the symbolic language of chemistry. There is a stead growing body of research that suggests that the use of visual tools helps students' transition between these levels of representation and their achievement in science is generally supported by direct access to multimedia modes of representation (Ardac & Akaygun, 2004).

According to Gilbert et al. (2008) a central topic that often crosses these studies is the definition of the term "visualization". There are two conventions, in convention 1, visualization is a verb (to visualize something is to mentally act on it), in convention 2 visualization is a noun (visualization is something in the public realm). It was found literature approaching this issue in the sense of convention 1 that dealt with questions such as: How is a visual representation turned into knowledge? What are the mental processes involved in attaching a meaning to a representation? (Reiner, 2008). Like it was mentioned before, there is another trend of research that uses the term visualization in the sense of convention 2, a noun, something that has been placed in the public realm in either a material object, visual, verbal or symbolic form. Here it was found several studies (Wu, Krajcik & Soloway, 2001; Ferk et al., 2003; Kozma & Russell, 2007a; Arroio & Honório, 2008) that by using a different approach try to evaluate the use of different kinds of visualizations in chemical instruction.

In addition to what was mentioned before, it must be considered that according Kozma & Russell (2005) the use of these visualizations (external representations) could be supported by two different learning theories: the *cognitive* theory and the *situative* theory. In this work authors propose the use of a situative theory to complement the cognitive theory of multimedia learning. The situative theory characterizes conceptual learning as result of social interactions. From this perspective a classroom is a community of practice where pupils are engaged in activities teacher-oriented, which interact with each other and with the tools that are in the setting. According to these authors, this approach is particularly interesting when the goal is learning science as an investigative process "students became chemists" (Kozma & Russell, 2007b, p. 121). When the learning focus is the acquisition of important chemical concepts and principles, the use of the visualizations must be supported by the cognitive theory. The cognitive theory admits an explicit focus on the individual students' reasoning and their brain architecture (memory system etc.). Reasoning is treated as an internal mental phenomenon.

As it was said before the availability of powerful computers made possible the design of several visualizations with scientific models, especially dynamic models, simulations and interactive modelling software that can be displayed and manipulated in a virtual format. In a literature review on this area we found some recent studies (Justi & Gilbert, 2002a; 2002b; Justi & Gilbert, 2003) that investigate the teacher's views/knowledge on the nature of models and modelling that point out the need to work these concepts in pre-service and in-service education. In their research they found teachers with less than satisfactory understanding of the notion of "model" which has implications on their teaching approaches on this concept, so on this training we gave an especial attention to the model notion.

In science education and especially in chemistry teaching the problem is becoming serious, beside the traditional 3D concrete molecular kit and the statics 2D images; teachers are using frequently virtual images (statics or dynamics) from several software available every ware. According Newton and Rogers (2001) in order to achieve learning benefits from ICT teachers must entail three types of skills: operational skills, procedural skills and pedagogical skills. The operational skills concerns the manipulation of the computer and features in the software, the procedural skills concerns the manner in which the visual tools are employed for the purpose of achieving learning benefits, and the pedagogical skills will be the planning, adaptation and the

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tailoring supported on ICT by which the teacher transforms his or her own comprehended ideas so that they may be learnt by students. Here we have the presence of a technological dimension which associated to the Pedagogical Content Knowledge (PCK) indicated by Shulman has been described by Koehler and Mishra (2005) as Technological Pedagogical Content Knowledge (TPCK). Webb (2010, p.181) has expressed the expanded component of required knowledge as "knowledge of how the wide range of technologies available my support the (subject) content to be taught and which pedagogical approaches are appropriate.". With this work we try to bring some contributions about the pedagogical knowledge needed to teachers use visual tools in a profitable way analyzing the impact of a training program on teachers' conceptions and attitudes on visualizations. With the development of this work we try to answer the following questions: "What are teachers' previous conceptions about the use of visualizations in science education and its role in learning?" and "What was the impact of this training on this issue?"

Methodology of Research

It was adopted a qualitative approach in this research, focused on the process, aiming to investigate how in-service teachers (n=14) enrolled in a teachers' training course of 40 h, understand the nature and the role of visualizations in science teaching as well as the impact of this training. The training course exposed them the learning theories (sociocultural and cognitive) that can support the use of these tools, especially multimedia environments. It was also discussed the nature and role of the models in science. During the training teachers were invited to build in group teaching learning sequences (TLS) about some science content using visualizations. At the beginning a questionnaire to identify some previous conceptions on this issue have been applied and analyzed. This questionnaire had two parts, the first one had eighteen open-ended questions and the second one focused on the model notion had seven questions about seven distinct aspects of the model notion (Nature, Use, Entities, Uniqueness, Time, Prediction and Accreditation). To each of these seven questions teachers had to choose from three or four categories (multiple choice questions), the one or the ones, that they thought that were corrects. The seven distinct aspects of the model notion and the categories were translated to Portuguese and adapted from the work of Justi and Gilbert (2003). On a later stage it was analyzed the TLS made by them and the audiovisual record of their oral communications to the class. At the ending of the training it was realized a semi-structured interview with each group with the purpose to clarify some issues that appear during their TLS presentation and to indentify the impact of this training program.

It was choose this qualitative approach which according Lüdke and André (1986) allow us to use the natural setting as primary source data, i.e. the teacher enrolled in a training program. According to Bogdan and Biklen (1994), the use of interviews is the best approaching tool to study people that share a particular feature. What they share between them will be revealed when they talk about their perspectives rather than when they are watched during their activities.

Sample

This study was conducted with fourteen science teachers from public Brazilian school. Four of them had a graduation in biology and were teaching only natural sciences or biology to elementary and high school pupils. The others had a graduation in chemistry and were teaching chemistry to high school pupils. These teachers had a wide range of teaching experience that goes from 3 years to 20 years, but the most part of them had less than 10 years of teaching experience.

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Training Program

The training program named "The usage of multimedia tools to study contents from chemistry High School" took 40 hours and was distributed into 10 sessions of 4 hours. The main purpose of the training program was to provide teachers with a theoretical framework mentioned on the introduction. The worked topics were:

- The usage of models and visualization in science teaching, with focus on chemistry;
- Vygotsky Sociocultural Theory, Dual Coding Theory (Paivio, 1986), Cognitive Load Theory (Sweller, 2003), Multimedia Learning Theory (Mayer, 2001);
- Features of some visual tools (concrete models, 2D and 3D images, animations, simulations and molecular modelling software).

Throughout this training program teachers were invited to build in group one TLS to teach some science content (preferably on chemistry) supported by visual tools and to make an oral communication to all the class followed by a group discussion. The outcomes from the first part of the questionnaire were analyzed through a content analysis, building a set of categories suitable with the research questions.

Results of Research

First it is going to be presented the outcomes of the first part of the questionnaire with 18 open-ended questions who aimed to identify the teachers' previous conceptions about the use of visualizations in science education and its role in learning. It was also wanted to find out the contribution of their graduation, literature/authors knowing by them about this issue, and conditions/support given by schools/police makers to work with these tools. Here it is going only to be presented the results of the first question: What are the teachers' previous conceptions about the use of visualization in science education and its role in learning? On Table 1 it is presented the outcomes from the first part of the written questionnaire related to this question.

Table 1. Categories and subcategories from the Questionnaire (1st part).

Research Question	Category	Subcategory
What are teachers' previous conceptions about the use of visualizations in science education and its role in learning?	Frequency on the use of visualizations	
	Type of the most used visualizations	
	Type of science contents where visualizations are most used	
	Pupils' receptivity/interest to the use of visualizations	
	Reasons to use visualizations	
	Criteria on visualizations choices	
	Theoretical concepts	Visualization
		Image

The results showed that seven teachers introduce these tools frequently on their classroom, one teacher referred very frequently, four teachers mentioned rarely, and two teachers referred that they had never used visualizations. The type of visualizations most used are statics images and concrete models, nevertheless, some of them referred also video, and

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only three mentioned the use of simulations and animations. The chemistry contents where these resources are most used are: atomic models, periodic table, solutions, thermo chemistry, organic chemistry, chemical bonding. In natural science they mentioned: astronomy, human body and living creatures study. Three teachers mentioned that they use visual tools all across the pupils' curriculum. When talking about the receptivity and pupils' interest all of them that used these tools referred that pupils react very positively to these tools.

On the category "Reasons to use visualizations", the majority of the teachers said that was to "*make easier the understanding of the concepts*" or "*improve the student' comprehension of the content*", but some teachers also referred that it was to "*make the class more pleasant*", to "*arouse the interest*" or to "*make the abstract more concrete*". One teacher said that was to substitute practical work and, for two teachers, its use is to provide students with "*spatial vision*", and the need to work with different languages.

When they talked about the criteria to choose each specific type of visualization the most common answer was "*to be [the visualization] related with the teaching content*", nevertheless, some teachers also referred the students' age and in the multimedia tools, the length time. One teacher mentioned that this choice is done according the students' background and with the level of the students' cognitive development, other teacher referred the resource complexity level. Another teacher said that this choice is done according the availability of the tool.

Concerning the theoretical concepts, the answers were very heterogeneous, to some teachers, the term visualization is related to the capacity to interpret an image "*the capacity to elaborate in an abstract way a model or an image*" or "*the watch effect*". For other teachers it's a visual tool "*what we see*" or "*images with or without animations*". When it was asked them about "Image", half of the teachers said synonymous: picture, illustration, draw, and photo. The others gave very diverse answers, like for instance: "*a stimuli to reflection*", "*graphic representation of objects and persons*", "*a visual tool that allow as to have ideas about a given subject*" or "*something that we can visualize*".

The results of the second part of the questionnaire related with the model notion are presented in the Table 2. The table shows the teachers' option to each aspect of model notion and associated categories. The 14 teachers were identifying by T1, T2… to T14.

Table 2. Teachers' options by aspect and associated categories (2nd part).

Aspect	Category	Teachers' options by aspect and categories
Nature		
A model is:	a) A reproduction of something.	T3;T7;T11
	b) A representation of the whole of something.	T1;T2;T3;T4;T6;T8;T9;T10;T12;T13
	c) A representation of part of something.	T14
	d) A mental image.	T2;T5;T6;T13
Use		
A model serve as:	a) A standard or reference to be followed.	T3;T6
	b) A visualization enabling a person to 'see' a phenomenon.	T6;T7
	c) A way of supporting creativity, the imagining of new contexts and the creation of new ideas.	T2;T4;T5;T8
	d) A way of understanding or explaining something.	T1;T2;T4;T6;T7:T8;T9;T10;T11;T12;T13;T14
Entities		
The entities of which models are composed are:	a) Objects.	T3;T6;T7;T11;T12;T13;T14
	b) Events.	T7;T13

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	c) Processes.	T2;T4;T6;T7;T13
	d) Ideas.	T1;T2;T4;T5;T6;T8;T9;T10;T11;T13
Uniqueness		
	a) Only one model, the 'correct model', is possible for a particular phenomenon.	T14
	b) A given model is only one of several available for a phenomenon.	T1;T3;T6;T11;T13
	c) A given model is only one of several in an historical sequence.	T2;T4;T5;T7;T8;T9;T10;T12;T13
Time		
As for the stability of a model over time:	a) It cannot be changed.	
	b) It can be changed when problems with its nature are identified.	T5;T6;T13
	c) It can be changed when problems with its use are identified.	T3;T7;T13
	d) It can be changed when problems with its explanatory adequacy are identified.	T1;T2;T4;T6;T7;T8;T9;T10;T11;T12;T13;T14
Accreditation		
The accreditation of a scientific model is given by:	a) The individual producing it.	T13
	b) A group in society.	T7;T8;T13
	c) The community of scientists.	T1;T2;T3;T4;T5;T6;T7;T9;T10;T11;T12;T13;T14
Prediction		
	a) A model cannot be used to make predictions about behaviour or properties.	T7
	b) A model may or may not be used to make predictions about behaviour or properties.	T1;T3;T4;T5;T6;T8;T9;T12;T13;T14
	c) A model can be used to make predictions about behaviour or properties	T2;T10

To answer the second research question "What was the impact of this training on this issue?" the TLS elaborated and presented to the class were analyzed, as well as audiovisual recording of their oral communication followed by the group discussion. It was also analyzed the transcripts of semi-structured group interview.

It only will be presented the outcomes of two categories which allow as to make a comparison and to answer that second question. The chosen categories were: reasons to use visualizations, and criteria on visualizations choices. It is going to be presented the outcomes of two of the four interviewed groups.

The first group presented a proposal (TLS) to study "Physical state changes" to eighth grade with 3 lessons of 50 min. They used concrete models, static images, an animation, a simulation, one modelling activity and a small interactive virtual game. They present a very well structured planning using a theoretical framework on ICT area (Morais & Paiva, 2007) and mentioned that "*we must embrace them harmoniously with the other curricula components [...] and not just an appendix or a peripheral resource*". They mentioned that they insert these tools as mediation tools, the animation will be to "*get a symbolic representation of the* *particles movement and aggregation…*" and the modelling activity will be to give students the "*opportunity to build, testing and socialize mental models*". During the presentation they reinforce the notion of to "*link this issue to pedagogical questions*", "*make ICT have a meaning inside the context that we put the students*", they emphasize clearly the use of this tools in a knowledge building perspective where the focus is on the interaction between students, teacher and "*all the these resources*". When questioned by its colleagues on which criteria they use to choose these tools, they mentioned the "*complexity of the resource*", "*the previous students' knowledge*" avoiding images that could create misunderstandings. Here, it was also clear the usage of a model as a representation and the image is seen like a sign, however in the semi-structure interview they showed difficulties in give a verbal definition of image, associate them to synonymous words (draw, picture, etc.) or "*something that we can use to check contents*" and "*a way to insert contents*". Nevertheless, when they talked about model, they showed a clearly understanding verbalizing as partial and limited representation of something based on a theory. In the same way they related visualization with interpretation, "*the way we process images*", but also connecting with resource.

On the interview they stress that the reasons to use these tools has changing, their use is now much more related to knowledge building, and in this sense, today on their practices they ask themselves if certain resource is adequate, if the students are enjoying because it's "*funny*", or if it's really contributing to students' apprenticeship. They said that this training brought this questioning and they choose now more carefully this type of resources especially multimedia tools and they have more concerns on "*not pass misconceptions*", recognizing the strong impact of the visual language.

Now it is presented the same outcomes for the second group that build a proposal about "Melting and boiling point" and "Chemical and physical transformations" to high school for three lessons of 50 min. This group makes a TLS based on the use of multimedia software produced by the book's editor adopted on their school. They justified this use by writing "*multimedia technology can make learning more exciting and relevant to students, through the combination of different resources, stimulating them in several ways*".

Throughout the oral communication of the TLS, they said that they felt "*almost forced*" to use these resources and they feel that is very hard to compete with pupils regardless to technology. They said that they cannot use (visual tools) just because is "*pleasant*", the students are already living on these environments. They feel the need to keep students' attention, but without losing the focus, i.e., what is the main purpose to use these tools. For them the major challenge is to have the notion that multimedia environments have several functions and teachers need some support to can use them properly, willpower and school conditions.

They referred that they always have fear to introduce misconceptions that are very hard to fix because what it's obvious for them it's sometime opaque to students. They also mentioned that these resources are useful to replace practical work because they save time and money, but they recognized that the ideal it's to have some practical work. They believe that these resources can be very important for students with special educative difficulties because they allow them to interact with the class according their difficulties. They also believe that these tools could bring to students a different look to science and mentioned that this training made them questioning about the reasons and criteria to use and to choose visualizations. On the final interview they associated image to a sign, but still had some difficulties in giving a clear definition. They highlight that the bigger change occurred on the model notion, referring that now when they use models in classroom they stress that they are useful for some explanations according some theory.

They related visualization with assigning meaning to an image and stress its importance in chemistry in order to build mental models and then the need to use multiple representations. They stress that this theoretical framework had changed their perspective about these resources,

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being now conscious that students may not interpret images in the same way that they do, and always as possible they try to understand what the student build from each image. Nowadays they feel more judicious on their choices, making deeply analyzes of images, thinking not only on the "*colours*", but also on possible misunderstandings that they can transmit trying to work on that with students.

Discussion

Analyzing now the outcomes of the sample it can be said that more than 50% of the teachers use visualizations, mainly static images and concrete models, which are easier to access and less complex in technological terms. In Chemistry they are used specially in contents where the abstraction is needed or the tri-dimensionality is very important to understand the concept. The reasons to use visualizations, in accordance with the data from the second part of written questionnaire on the aspect *Use* (option d), were related to model explanatory function, so this sample has been using visualizations to "*make easier the understanding of concepts*", no considering their role in building knowledge. This fact seems to have suffered some changes, but we need more data from their practices to confirm this hypothesis. From their TLS's and looking their answers, we can recognize a new way to conceive these tools that we hope that has some impact in their classes.

It became very clear on their interventions a greater concern related to the use of these tools, searching for a theoretical background that give some sense to the use of these tools behind their attractive role. This fact has a reflection on the criteria, all teachers referred that they are much more careful on their visualization choices, trying to anticipate on their practices the impact of each visualization, and make latter on an assessment of what meaning was giving by students.

Concerning the theoretical concepts of image, model and visualization it was detected some changes. On the previous questionnaire, half part of the teachers enrolled in the training, on the definition of image only mentioned synonymous, at the ending it could be seen an increase on the notion of representation, even they showed some difficulties on giving a verbal definition on the interview. This was a concept that probably should have been better discussed.

On the model notion, they show at the ending a better understanding and security on their intervention, probably because it was given a great emphasis on the training program on this issue. As we can see on Table 2, it can be said that their previous conception of model it was complex and incomplete, nevertheless we try to found some patterns. On the *Nature* aspect, these teachers considered mainly that a model is a partial representation of something; however, not all the answers were coherent. For instances T3 considers that a model is a reproduction and a representation (categories a) and c)), and only four teachers related with mental model. On the *Use* aspect, these teachers gave a great relevance to its explanatory function almost not considering its predictive function (category c).When it was analyzed the aspect *Entities* it was found an unexpected result, it was expected that they choose perhaps mainly the first category (a) Objects and not the last category (d) Ideas. According with scientific practices they would have included all four categories what shows fragility on this aspect. Concerning the aspect *Uniqueness*, it was also obtained an unexpected result according some research that refers the absence of historical science discussions on science teaching. This sample chooses mainly the category c), which relates models to an historical construction. On the aspect *Time* on concordance with previous answers they considered that the model should be changed when there are some problems with his explanatory function. The few choices on the options b) and c) also show some fragility on the model notion. On the *Accreditation* aspect, the great majority of teachers think that she must be given by a scientific community, however, we could see some inconsistent choices from teachers T7 e T13. On the last aspect *Prediction*, it was found a great level of insecurity. The majority option on category b) revelled that they aren't aware of this function (prediction) in science, which is in agreement with previous answers (*Use* and *Time* aspect).

Lastly regarding the concept of visualization, on the previous questionnaire only a few teachers were aware of visualization as give meaning to an image, now on the final interview they put more emphasis on the image interpretation and its role on building mental models.

Conclusion

According to these results it can be said that these in-service teachers have been using visualization in an intuitive way, based on evidences from their practices they realized that these tools somehow helped students learning. Sometimes we have references to some external pressing to use these tools. From the questionnaire it can be seen some lack on the theoretical background that we think that has improved with this training. The theoretical conceptions about model, image and visualization were superficial and sometimes became misconceptions. The theoretical discussion on the theories from cognitive area and sociocultural area revelled to be very useful, increasing teachers' knowledge about the potentialities of these tools and their learning impact. We believe that we were able to soften the naïve vision that these resources can only make classes more pleasant, and so we think that the training had a positive impact and we hope to have contributed to make them more reflexive when using visualizations.

Acknowledgements

The authors thank the CAPES Brazilian agency for financial support (scholarship).

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Received: *September 15, 2011* Accepted: *October 26, 2011*

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