Using Dynamic Visualizations to Enhance Learning in Physical Geography

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**INTRODUCTION**

Physical geography is a domain where many misconceptions and learning problems have been reported through the years in all ages, from elementary education through to university level (Siegburg, 1987; Schee et al., 1992; Neighbour, 1992; Harwood & Jackson, 1993; Purnell & Solman, 1993; Forsyth, 1995; Keliher, 1997; Livni & Bar, 1998; Bartlett, 1999; LeVasseur, 1999; Gobert, 2000; Gerber, 2001, Verdi & Kulhavy, 2002; Morgan & Tidmarsh, 2004; Pedersen et al., 2005; Cooshna Naik & Teelock, 2006).

According to the literature, the problems that appear in Physical Geography teaching and learning can be classified in the following five categories:

1. **Terminology**: Students cannot describe geographic characteristics using geographic terminology (Harwood & Jackson, 1993; Keliher, 1997; Golledge, 2005).
2. **Interpretation**: There are misconceptions and difficulties in the interpretation and explanation of geographic characteristics and phenomena. This is quite often observed among elementary students (Schee et al., 1992; Neighbour, 1992; Livni & Bar, 1998; Pedersen et al., 2005).
3. **Language**: There is a difficulty for students to express themselves verbally, especially using geographic terminology. Pupils perform better using alternative methods, such as sketching geomorphologic evolution. There is no problem in perception, but rather in the usage of language (Harwood & Jackson, 1993; Keliher, 1997; Gobert, 2000; Golledge, 2005).
4. **Symbols**: Misconceptions and difficulties arise from the frequent use of symbols for geographic characteristics rendering. Symbols mainly concern the color attribution of hypsometric levels, discrimination between mountains, hills, valleys and plains, catchment basins and erosion levels (Fredrich & Fuller, 1998; Nordstrom & Jackson, 2001; Livni & Bar, 2001; Verdi & Kulhavy, 2002).
5. **Static media**: Natural phenomena have a dynamic character that is difficult or impossible to be represented in a static way (Siegburg, 1987; Schee et al., 1992; Neighbour, 1992; Livni & Bar, 1998; Cooshna Naik & Teelock, 2006). Misconceptions mainly concern changes on the earth anaglyph and especially the phenomenon of erosion (Gregg, 2001).

The proposals for the solution of these problems can be classified in the following three categories, as the critical review of the preceding literature shows.

1. **Integrated learning environments**: The design and implementation of integrated learning environments involving active participation of the students is of major importance. Specific didactic goals and learning activities, as well as the elimination of cognitive overload resulting from the huge volume and density of information are also important elements.
2. **Diversity in expression**: Variety in the way students express themselves beyond the verbal method is proposed, both for the construction of geographic knowledge and for evaluation purposes.
3. **Experience enhancement**: The huge space and time scales concerning geographic phenomena are the main cause of misconceptions. Realistic representations with natural semantics as well as different spatial and temporal scales appear to offer a solution for the difficulties in physical geography teaching and learning.

Information and communication technologies (ICT) support integrated learning environments, diversity in expression, and experience enhancement.
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This article presents a critical review of the ICT used in physical geography learning. It also proposes interactive dynamic visualizations with an example on the phenomenon of erosion, and presents the results of a qualitative empirical research involving elementary school pupils.

ICT IN PHYSICAL GEOGRAPHY TEACHING

Computer assisted instruction and learning (CAI, CAL) have been applied to geography education for more than 30 years. Integrated educational applications were developed during the nineties, with the first positive learning outcomes appearing only recently.

The main reasons are the late technological boom in graphics and spatial representations, and the delayed development of interactive computer-based educational environments dedicated to geographic knowledge construction.

We believe that physical geography is a domain of special interest for the design of CAI and CAL applications, exploiting spatial technologies and high resolution graphics. Various types of ICT are proposed for students’ motivation and active participation in the didactic process.

Regarding the evaluation of CAI and CAL systems for geography teaching, the results are poor and mainly concern university students. A worldwide empirical research showed that the use of ICT in Geography education was limited, whilst featuring their effectiveness in geography teaching and learning (Gerber, 2001). This is also highlighted by the recent published work (Morgan & Tidmarsh, 2004; Golledge, 2005; Pedersen et al., 2005; Shin, 2006 and references therein).

The purpose of the review that follows is the search of the proper technological approach for the design of an integrated computer-based learning environment. Thus, the research papers are classified according to the type of technologies used in geography education.

Geographic Information Systems

Geographic information systems (GIS) provide a powerful environment for the management and presentation of geographic information using different levels for the representation of different types of information.

Nellis (1994) and Keiper (1999) reported on the difficulty in GIS use at elementary level. Even for university students the results were not encouraging when they were taught spatial skills using GIS (Chen, 1998). The same problems were found by O’Kelly (2000) and Lloyd (2001) in all educational levels. Huang et al. (2001) spotted the problems with GIS in their lack of three-dimensional visualization and interactivity. Kerski in his survey of 1520 high schools that use GIS software reported that the effectiveness of GIS in teaching and learning is limited (2003). Positive learning outcomes reported only recently by Shin in her study with fourth grade students. The author found that using GIS with a well designed instructional module helps students improve their geographic knowledge and map skills (2006).

Almost all the researchers propose constructivism as the pedagogical support concerning the use of GIS in education, proposing authentic learning activities. It seems that GIS are difficult to introduce in education and offer a limited method of geographic information representation for knowledge construction and metacognitive skills acquisition.

Internet Tools and Applications

Internet, Web sites and portals are a huge resource of dynamic information. Virtual universities, geological institutes, meteorological stations and satellites are some of the resources for geographic information. Their immediate exploitation in the educational process is often difficult, since the material is not provided through an educational context.

Suthren (1998) proposed the replacement of educational geomorphologic posters with virtual representations published in web pages. Although the author pointed out the exploitation of ICT in cases where other media are not appropriate, he simply transferred geographic information from a traditional to an electronic format. Hill and Solem (1999), Hurley et al. (1999) and Taylor (2000) summarized the value of the Internet as an environment for up to date content delivery, online hypermedia context, interactive evaluation, tool for communication and collaborative learning. The authors proposed online collaborative learning environments based on social constructivism. Harrison et al. in their large scale study on the use of ICT and its relationship with performance in examinations reported a relatively
high usage of Internet to find geographic information (2004).

In general, approaches using the Internet as a tool for geography teaching have a technocratic point of view, emphasizing technologies and tools rather than pedagogy and instructional design.

**Hypermedia Environments**

Krygier et al. (1997) developed a hypermedia application for geography and earth sciences teaching based on linked multiple representations of information such as text, maps, tables and graphs. Their proposal followed the general guidelines for hypermedia educational software without special mention of geographic education principles. Kraak and van Driel (1997) proposed hypermaps, multimedia systems with geographic references. Results from the use of hypermedia software in geography education have been published by Boyle et al. (1997). Technology proved to be strong motivation for 54 geography students who developed a positive attitude towards ICT, but the learning outcomes were limited. Recently, Cooshna Naik and Teelock, in a study with pupils aged 8-10, reported positive results on their attitude towards a hypermedia application but not on learning outcomes (2006). Although pictures of any kind such as illustrations, photographs, animation, video, etc play an important role in physical geography, there is no much work on educational hypermedia applications. Overall, a theoretical goal of contributing to a cognitive theory of how students learn from multiple representations and a practical goal of contributing to the design of effective multimedia instruction have to be set in order to reach positive learning outcomes (Mayer, 2002).

**Virtual Environments**

Virtual reality technologies offer a new context for the development of educational environments, based on three dimensional spatial representations. An educational virtual environment is the virtual environment that has one or more educational objectives, provides users with experiences they would otherwise not be able to experience in the physical world and redounds specific learning outcomes (Mikropoulos, 2006).

Mikropoulos (1996) designed an integrated environment for physical geography teaching combining virtual environments, GIS and multimedia content. Virtual field trips have been proposed and used by many researchers and educators as an alternative approach to field work. Moore (1997) combined virtual field trips with multimedia content and geographic data bases and found positive learning outcomes with Geography students. Hurst (1998) with a similar approach had no such evidence. Stainfield et al. (2000) proposed interactive virtual field trips, temporal and spatial modelling, without, however, presenting any result from empirical studies.

**Simulations and Visualizations**

Simulations and visualizations in earth sciences teaching have been proposed since 1997 (Mitas et al., 1997). The poor learning outcomes observed, are mainly due to the lack of didactic transformation of the scientific knowledge, as well as the use of symbols (Edelson and Gordin, 1998; Friedman & diSessa, 1999). Simulations presenting geographic information through numerical data and graphs gave no positive learning outcomes (Pinto et al., 2000; Renshaw & Taylor, 2000). Marlino (2001) has proposed visualizations of natural phenomena, without reporting any learning outcomes. References regarding realistic visualizations using natural semantics without symbols have not been found, except the positive learning outcomes reported by Bellos et al. (2003) who exploited visualizations and virtual environments representing real and imaginary landscapes.

Several technologies and approaches have been designed for physical geography teaching and learning. The main problem is the lack of empirical studies for the evaluation of this software and the absence of results in terms of learning outcomes. The lack of a proper methodology for empirical studies in geography education had been noted since 1992 (Schrettenbrunner, 1992), confirmed in 1999 (Boehm & Petersen, 1999) and 2000 (Welford & Fouberg, 2000) and continues until recently (Cooshna Naik & Teelock, 2006). Although ICT support integrated dynamic environments, diversity in expression, and experience enhancement, it seems that the problems posed by terminology, interpretation, language, and the use of symbols are not yet sufficiently faced by any of the above approaches.

It seems that today’s proposals of ICT in geography education are in accordance with Freeman’s proposals (1997), which are:
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- Resources for content retrieval
- Real situations modelling tools
- Tools for enquiry learning
- Communication tools
- Tools for measurement of natural phenomena.

We believe that these have to be integrated in educational environments with certain didactic goals and learning activities. Taking into account all the above, as well as the lack of positive learning outcomes from the ICT approaches in geography teaching, we propose the use of visualizations in physical geography learning.

**VISUALIZATIONS IN PHYSICAL GEOGRAPHY LEARNING**

There are two main difficulties in physical geography teaching and learning for pupils and students; the use of symbols for the representation of geographic information through various media and the static character of media. Researchers propose dynamic means for the study of geographic phenomena in space and time, without the use of symbols (Siegburg, 1987; Schee et al., 1992; Rose, 1996). They propose geographic information visualizations based on simulations, representing characteristics and phenomena in a realistic way. As the bibliographic review has shown, there are no references regarding the design, development and evaluation of computer-based educational environments supporting the above proposals.

The main component, as in any didactic process, is the didactic transformation. The proper didactic transformation, proposed in this article, is the simulation-based realistic dynamic representation of geomorphologic characteristics and phenomena.

We define a simulation as the representation of an object, a natural or social phenomenon by software, where the user may manipulate conditions and parameters for study purposes. A simulation causes the machine to respond mathematically to data and changing conditions as if it (the machine) was the same object or phenomenon.

A simulation in the learning process places the learner in situations similar to reality, providing realtime feedback to questions, decisions and actions. A simulation has to be interactive giving the capability for changing those parameters that are important according to the didactic transformation. A simulation has to motivate the learner through multiple representations in order to make the relationship between the parameters obvious to them. The results of a simulation can be represented through a variety of ways, mainly as numerical data and graphics. Simulations are powerful tools in the learning process through visualizations, defined as optical representations of information and mental images. Optical hermeneutic experimentation is what we mean by educational visualizations. Consequently, we argue that animations that are not based on modelling and simulation processes do not have a great value within the learning process.

The visualizations we propose follow the basic principles that are accuracy, representativeness, visual clarity and interest (Sheppard, 2001).

Our visualizations also incorporate the following attributes which we believe are of greatest importance in the learning process:

- **Natural semantics:** Visualizations are realistic representations without the use of symbols. They represent the natural terrain together with hydrography, flora and other factors affecting the landscape’s evolution.
- **Spatial scale alterations:** Geographic characteristics and phenomena are represented in small, screen size, scale.
- **Temporal scale alterations:** Long geological eras are integrated in small time periods under the user’s control.
- **Exploration and investigation of alternative realities:** Students experience cognitive conflict and reach conclusions by inducing different scenarios for the evolution of phenomena.
- **Experience enhancement. New experiences:** Visualizations enhance, or provide new experiences concerning phenomena which are impossible to study through field work because of their huge spatial and long temporal scales.
- **Interactivity:** Students may change parameters involved in the simulated phenomena, investigate natural processes, foresee consequences and compare environments.
- **Immediate feedback:** Students immediately discover the results of their actions.
- **Multiple representations:** The combination of multiple representations such as visual and verbal, contributes to the learning process.
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- **Reusability**: Visualizations may be integrated in more than one context, depending on learning styles or needs
- **Hypothesis formation**: Dynamic visualizations provide a tool for hypothesis formation related to the geologic history of the simulated places
- **Evaluation of geographic theories**: The critical attitude towards computer models allows students to discriminate between models and reality and acquire a scientific attitude
- **Hypermedia environment**: The integration of visualizations in hypermedia environments combining multimedia content and learning activities, gives direct access to resources for the support of the learning process.

Dynamic visualizations are more valuable in the learning process when they involve multiple representations, especially when they combine visual and oral information. Learners are more likely to engage in productive cognitive processing when corresponding images and words are presented at the same time. Simultaneous presentation increases the chances that corresponding images and words will be in working memory at the same time, thereby enabling the learner to construct mental connections between them. This cognitive processing should result in deeper understanding (Mayer, 2002).

There are two tensions on the proper role of modelling in the didactic process. One proposes the use of already-constructed models of phenomena for demonstration purposes, while the other forces students to construct their own models to describe phenomena (Wilensky, 2003). The pure constructivist point of view is the later one, but there are other intermediate states between the two above. One of these, exploited by Wilensky (2003) and proposed in this article, is the use of pre-constructed visualizations as investigative tools. They involve changeable parameters, allow the user to modify settings and conditions and study the model’s behaviour. Two advantages of this approach are time saving and the necessity of low level computer literacy by the students.

In the following, ‘landforms’, an integrated educational environment that involves visualizations concerning the effect of running water, that is the phenomenon of erosion, is presented. The visualizations represent real phenomena using natural semantics and users may observe, manipulate and perceive the evolution of landscapes without symbols such as colour codes. An empirical study with 13 pupils investigates the role of the dynamic visualizations in their ideas development and learning.

**LANDFORMS: EDUCATIONAL SOFTWARE FOR PHYSICAL GEOGRAPHY**

The bibliographic review presented in the previous sections showed that although elementary pupils are interested in natural phenomena and have misconceptions about them, there are no references to the effect of running water on the earth’s surface. Moreover, there are no references regarding the design of educational software on phenomena such as erosion and landform creation.

In a previous empirical research, we studied pupils’ ideas about geographic phenomena (Bellou et al., 2001). The results showed that the majority of children aged 9-11 had a very limited understanding of terrain evolution. Children mainly faced difficulties in the following areas:

1. It was difficult to accept the idea that the terrain can dramatically change, so that a canyon may one day be transformed into a valley
2. They could not represent the different phases of the evolution of the landscape in time
3. They could not accept the causes of the formation of riverbed and Delta.

In order to overcome children’s difficulties, we have designed and developed ‘landforms’, an educational environment comprising visualizations of the phenomena under study. The software has three main parts, dynamically presenting the transformation of a canyon into a valley, the erosion of a riverbed and the formation of a Delta. Each part consists of three sections. The first involves visualization with a time bar for moving forward or backwards in time or even freezing evolution at will. The second combines the visualization with an oral presentation describing the phenomenon under study. The last section consists of interactive learning activities some of which include visualizations.

The visualizations were created using four different software packages. Firstly, digital landscapes based on...
real data including the geographic characteristics under study, were created using a package for the creation of virtual landscapes (VistaPro 4.0). The landscapes were processed in image processing software in order for the appropriate landforms to be constructed. The landscapes successively manipulated by VistaPro in order to give a series of digital landscapes representing a realistic evolution of the landforms due to the effect of running water. After that, the digital landscapes were imported into morphing software in order for the temporal evolution of the landforms to be created in a form of dynamic visualizations. Finally, the visualizations representing successive time periods were connected using video processing software, to allow the final visualization to be produced. The result was in two forms. The first was the visualization with the time bar, for the user to ‘move’ in time. The second was the visualization combined with oral representation, a narration about the terrain’s transformation. Figure 1 shows three screenshots from the visualization representing the formation of a river Delta, caused by erosion.

Figure 2 shows one of the interactive learning activities. The pupil manipulates and observes two visualizations simultaneously, trying to discover the factor that causes greater erosion. This specific example shows two visualizations representing the same landscape with (top) and without (bottom) plant coverage.

The educational software is integrated in a hypermedia environment involving a glossary of geographic terms as a reference. ‘Landforms’ is easy for teachers and pupils to use, without having any special expertise in computers.

THE STUDY

We used ‘landforms’ in an empirical study with the following research axes:

- Investigation of the pupils’ initial ideas when observing the visualization as a succession of static images
- Investigation of pupils’ ideas after their interaction with the dynamic visualization
- Study of the pupils’ ideas development.

Sample

The sample was a class of 13 elementary pupils aged 10-11. All children had a basic level of computer use experience. The phenomena of erosion, deposition and river Delta were part of the elementary school curriculum.
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**Procedure**

The study was carried out in a real class environment, in the computer room. The procedure consisted of two phases. During the first one, each pupil observed the phenomenon of fluvial erosion deposition from a static visualization, a series of images. During the second phase, each pupil observed the same phenomenon as a dynamic visualization on the computer screen. During their interaction with the dynamic visualization, the pupils used the time bar of the visualization to ‘move’ in time, as well as the double presentation combining both visual and oral representations. They also completed a series of interactive learning activities. The only think the researcher did was to ask each one of the 13 pupils just after each phase to describe what they saw in the visualization and give explanations about the reasons for the changes they observed. Finally, they sketched the evolution of a landscape and the formation of Delta on a sheet of paper. A certain type of a landscape was already sketched, and the pupils had to sketch its evolution in two successive stages by themselves.

The research procedure lasted 45 minutes that is a one hour class.

**Evaluation Methodology**

It is considered that knowledge is the way of understanding a phenomenon and learning is a process of changing this way of understanding (Leung, 2000). Knowledge is described with qualitative terms that focus on the cognitive content of pupils’ answers. The evaluation of pupils’ answers shows that groups of pupils can be found to have the same level of understanding. Moreover, groups of pupils of the same age belong to different levels of understanding that build a level hierarchy.

SOLO (Structure of the Observed Learning Outcomes) taxonomy proposed by Biggs and Collis (1982), classifies pupils’ understanding in the following five hierarchical levels.

1. **Prestructural:** The pupil avoids or repeats the question, makes an irrelevant association.
In a transitional stage, the pupil inadequately uses a relevant datum.

2. **Unistructural:** The pupil selects one relevant datum and closes on that.
   In a transitional stage, the pupil selects two relevant but inconsistent data.

3. **Multistructural:** The pupil selects two or more relevant data, uses them inconsistently and reaches an alternative conclusion.
   In a transitional stage, the pupil recognizes inconsistencies but can not resolve them.

4. **Relational:** The pupil uses most or all relevant data, integrates it with a relating concept and reaches the right conclusion.

5. **Extended abstract:** The pupil uses abstract principles that show the specific example is just one of many possible results.

We have used SOLO taxonomy for the data analysis of our qualitative study, which resulted in different hierarchy levels expressing the development of knowledge construction. An additional reason for using the SOLO taxonomy was its application in geography teaching (Biggs & Collis, 1982).

Each pupil’s answer belongs to a level according to the following three components:

1. Detection of geographic characteristics and factors affecting the phenomenon under study
2. Association of characteristics and factors
3. Factual conclusion according to the above components.

We have detected the first four levels among the pupils’ answers, showing their development of understanding when they first observed the static images and later after interacting with the visualization.

**RESULTS**

The results presented in this article concern only one part of the software, that of the formation of a Delta. Figure 1 shows three screenshots from the dynamic visualization. As the time passes, erosion caused by rainfalls and running water alters the landscape’s morphology and the river’s shape. The river transfers the eroded materials such as clay, slit and sand, deposits them at its estuary, and a Delta forms.

All pupils found their interaction with the software interesting, declaring no tiredness at all.

We have categorized pupils’ answers into the first four SOLO levels, while we cite some of them below. We present each pupil’s answer after the initial observation of the images and then after their interaction with the visualization. The question each pupil was asked was “What do you think is presented here? Why is this happening?”

**Prestructural to Multistructural Level Answers**

Georgia: “The river is shortening because the grass grows around the lake and the ground starts changing.”

The pupil’s answer was classified at the 1st prestructural level, since her description was extraneous to the matter in hand and focused on irrelevant details.

Georgia (after interaction): “In the beginning the mountains were big and afterwards they started lowering. The river was made by the rain and a Delta appeared.”

Georgia’s answer was classified at the 3rd multistructural level, since she observed the changes in the landscape, as well as the Delta formation. She neither connected the factors affecting the phenomenon, nor gave an adequate explanation.

Vasso: “As time passes some stones get out of water.”

Her answer was classified at the 1st prestructural level. It could be at a transitional stage towards the unistructural level, since Vasso observed a datum, but did not consider the factors connected with the topic. Thus, she did not make any connection and did not explain any reason.

Vasso (after interaction): “As time passes the water runs, it washes stones out and a Delta is made.”

Vasso’s answer was classified at the 3rd multistructural level, since she reported some facts and reasons but did not explicitly explain the landscape’s changes and the way the Delta is formatted.
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Unistructural to Multistructural Level Answers

_Sotos:_ “Water found some obstacles changed its course and the Delta was formed.”

This pupil’s answer was classified at the 2nd unistructural level, since he observed one datum, the Delta, but did not associate it with erosion.

_Sotos (after interaction):_ “Heavy rains washed rocks and clay out and a Delta was made.”

_Sotos’ answer was classified at the 3rd multistructural level. It could be at a transitional stage between multistructural and relational, since he related the action of water to the Delta formation, but without giving any explanation._

Unistructural to Relational Level Answers

_Thanos:_ “A Delta formation is presented. The running water has found some obstacles. So its direction changed.”

This pupil’s answer was classified at the 2nd unistructural level, since he chose one relevant datum and stopped at that. He did not associate data and gave no satisfactory explanations.

_Thanos (after interaction):_ “The soil is washed out because of heavy rainfall and when the river reaches sea, it leaves some of the particles and loose stones.”

_After the interaction with the visualization Thanos’ answer was classified at the 4th relational level, since he reported the sequence of the facts, their reasons and he constructed a complete argument._

Multistructural to Relational Level Answers

_Tom:_ “Mountains started lowering. A river falls into the sea. The river washed mud out and it finally divided into four parts.”

Tom chose certain relevant data, reported on them but he did not connect them. He used some ambiguous expressions concerning the outfall of the water and he gave a description without any explanation. So, his answer was classified at the 3rd multistructural level.

_Tom (after interaction):_ “The area was firstly eroded because of rain and snow. Materials were moved away by the river and a Delta was created during their deposition at sea.”

_Tom used most of data in a generic way, associated it in a consistent way, gave explanations and presented the relations between cause and result. This pupil, after the interaction with the visualization, constructed an argument and reached a scientifically correct conclusion. His answer was classified at the 4th relational level._

_Simon:_ “It shows the changes coming from the river’s water and the Delta formation.”

_Simon’s answer was classified at the 3rd multistructural level, since he described the phenomenon without explaining the way the changes occurred._

_Simon (after interaction):_ “Water washed some materials out, and afterwards deposited them at the Delta. This way, the land expanded towards the sea.”

_Simon’s answer was classified at the 4th relational level after his interaction with the visualization, since he cited the facts in their order, associated them and gave explanations._

Figure 3 shows pupils’ SOLO levels concerning their ideas on Delta formation both after the observation of the images and after the interaction with the dynamic visualization.

There was a shift in pupils’ answers towards higher SOLO levels, after the interaction with the visualization. It seems that interactivity and multiple representations were strong attributes that contributed to reasoning, knowledge construction and meta-cognitive skills.

In order to by-pass the pupils’ difficulties in language and the use of proper geographic terms, we studied their sketches showing the evolution of a landscape and the formation of Delta. The geographic characteristics the pupils had to change were the mountains, the river and the Delta. Eight out of the 13 pupils drew both the
morphology and the Delta formation explicitly. The remaining five represented either the changes of the mountains and the river, or the Delta formation. All the pupils managed to overcome their language difficulties and express themselves by drawing the landform’s evolution. Although sketches are not a simple direct representation of mental images, they are considered as an effective tool to interpret the pupils’ internal representations and have been used to assess students’ spatial concepts (Shin, 2006).

**CONCLUSION**

This article proposes the use of dynamic, interactive visualizations with natural semantics for Physical Geography learning. The author designed and developed the educational software ‘landforms’, involving dynamic visualizations in a hypermedia context. The article also presents results from a case study investigating 13 pupils’ ideas on Delta formation both after their observation of static images and later after their interaction with the dynamic visualization. To our knowledge, this is the first work presenting empirical results from geographic dynamic visualizations representing phenomena in a realistic way without the use of symbols, following the proposals of many researchers (Siegburg, 1987; Schee et al., 1992; Rose, 1996).

The pupils’ ideas improved after their interaction with the dynamic visualization and multiple representations. Their answers were shifted to higher SOLO levels, indicating knowledge construction. Initial ideas and misconceptions concerning the causes for Delta formation diminished. The pupils’ ideas were shifted to scientifically accepted concepts that are that running water and river flow were the main causes for the anaglyph changes and Delta formation. There was not even one pupil who avoided answering. The pupils recognized all the geographic characteristics and their evolution in time. They mainly referred to terms from their everyday experience, which are integrated in the cognitive categories reported by Mark et al. (1999). The pupils’ meta-cognitive skills were activated during their involvement with the interactive learning activities that they all completed correctly.

Positive learning outcomes after the pupils’ interaction with the visualization were also confirmed by a series of the successive sketches they made, showing the landscape evolution and the Delta formation. This activity was designed for the children to be able to present their ideas without the geographic terminology which is difficult to use (Bartlett, 1999). These results are in coherence with those reported by Bartlett with students 13-16 years (1999) and by Gobert with pupils 10-12 years old (2000).

The results of the present study are consistent with those of others such as Friedman and diSessa (1999).
who advocate representations as an important instructional target. The multiple and dynamic representations led the pupils to cognitive processing that resulted in deeper understanding (Mayer, 2002). Moreover, the positive learning outcomes are similar to those of the author’s study with pupils using ‘landforms’ over a long period of study involving all three parts of the software, the transformation of a canyon into a valley, the erosion of a riverbed and the formation of a river Delta (Bellou, 2003).

The results of our case study highlight Friedman and diSessa’s principles for educational visualizations in Geography learning (1999). Our dynamic and interactive visualizations support understandings of representational aspects, intuitive perceptual interpretive capabilities that are the central prior resources on which we seek to build, and allow pupils to design new representations that are an additional avenue of creative engagement.

We believe that dynamic and interactive visualizations with natural semantics, spatial and temporal scale alterations, exploration and investigation of alternative realities, experience enhancement, immediate feedback and multiple representations provide a powerful tool for hypothesis formation, evaluation of geographic theories and explanation of geographic phenomena. A hypermedia context with related information and learning activities is also proposed for the integration of the visualizations in an educational environment with specific didactic goals.

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**KEY TERMS**

**Didactic Transformation**: The transformation of high level abstraction symbolic codes used for the description of scientific models, in a way that optimizes their comprehension possibilities in the educational process.

**Model**: A physical or ideal system created to represent a physical or ideal system at certain level.

**Natural Semantics**: Representations without the use of symbols.

**Optical Hermeneutic Experimentation**: Visualization based on modelling and simulation processes by contrast to artistic representation.

**River Delta**: A low, watery land formed at the mouth of a river. It is formed from the silt, sand and small rocks that flow downstream in the river and are deposited in the delta.

**Simulation**: The representation of an object, a natural or social phenomenon by software, where the user may manipulate conditions and parameters for study purposes. A simulation causes the machine to respond mathematically to data and changing conditions as if it (the machine) was the same object or phenomenon.

**SOLO (Structure of the Observed Learning Outcomes)**: Taxonomy proposed by Biggs and Collis (1982) that classifies students’ understanding in five hierarchical levels. SOLO taxonomy is used for the qualitative analysis of empirical data.

**Visualization**: Construction of a visual image in the mind. A graphical representation of data and concepts.