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Visual representations of the internet in greek school textbooks and students' experiences

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Abstract Our research is concerned with the visual representations found in textbooks used for the teaching of the Internet in Greek secondary schools. Visualization, as both the product and the process of creation, interpretation and reflection upon pictures and images, is considered here to be very important, as it is the only way students gain insight into the nature and function of the Internet, its size, complexity and invisibility. Initially, we attempted to analyze and reflect upon school textbooks' visual interpretations of the Internet. A scheme of categories of visual representations has been identified and reveals the characteristics of the textbooks' representations as well as their limitations. Sketch-comics and computer snap-shots are the more popular types of Vrep, although a considerable number of them cannot be characterized as accurate and few of them have an explanatory or complementary function in terms of the content presented in the text. We have also explored the impact on students' readings of two visual representations in one of the textbooks, used without any caption or textual information. The phenomenological aspects of the VRep seem to attract students' attention and create obstacles in conceptualizing the main idea conveyed in both representations, but when the field of ICT is implied and not clearly portrayed in the VRep, students face serious

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problems in recognizing the phenomenon. It seems that it is difficult for an image on its own to paint a thousand words.

Keywords Visual representations · Learning of internet · School textbooks · Students' experiences

1 Introduction

Curriculum materials play an important role in students' learning. Efforts have begun to develop an adequately valid and reliable procedure in order to judge whether or how well, curriculum materials match specific learning goals (AAAS—Project 2061 2006). Secondary school teaching and learning is dominated by textbook-oriented approaches (Tobin 1990) and this is also the case in Greece, where even the subject of informatics is taught in a traditional manner, just as any other subject, based mainly on textbooks.

Visual representations (VRep) in textbooks are important teaching and learning tools and have recently attracted research attention. The co-deployment of written language and visual representations is especially important for science textbooks which aim to lead non-expert readers to an understanding of the esoteric domain of a scientific field. Science textbooks "should ideally be authored in such a way so as to privilege converging and intentional interpretations on the part of the learners while discouraging divergent and unintentional readings" (Koulaidis and Dimopoulos 2005/06, p.244). Some research on the pedagogical role of VRep in school science has emerged recently but is still very scarce and fragmented (Schnotz et al. 1993; Pozzer and Roth 2003). VRep constitute a major component of secondary school texts. Roth et al. (1999) have adopted an anthropological point of view in studying representation practices in ecology. As they argue "The feasibility of this anthropological project lies in restoring to graph use its concreteness as real activity—the inspectable cultural practices of a community" (p.980). The pedagogy of photographs in high school science has been studied by Pozzer and Roth (2003) focusing on how the co-deployment of photographs and texts is structured, while the same authors have also studied the way photographs are received by the students and their effect in the learning process (Pozzer-Ardenghi and Roth 2004). Pedagogical aspects of visual representations in school Informatics textbooks are the focus of the present study, which adopts two approaches: analyzing the characteristics of visual representations of the Internet and exploring students' readings of two specific visual representations of the Internet.

The importance of understanding the internet and the services which citizens today are offered is well accepted, particularly so for computer education (Papastergiou 2005; Rogers and Finlayson 2004). At present there is no policy that directly addresses the need to develop learners'—or teachers'—mental representations of new technologies, and this may be an important missing element in changing the nature of learning with ICT in schools (Mavers et al. 2002). The internet has implications for the physical, cognitive, social and behavioural development of children and adolescents (Finkelhor et al. 2003; Katz and Rice 2002). In contrast to the extensive literature that has documented when, how and

why children come to understand natural, social and mental concepts, research into children's understanding of complex artefacts, such as the internet and computers, is sparse (Yan 2006). Adults' mental models are the ones that have mainly been studied (Papastergiou 2005). Secondary school students' ideas of the service of electronic mail (Kollara et al. 2000) and of the concept of Webpage (Spiliotopoulou and Karatrantou 2005), as expressed through drawings and explanations, have shown that their models develop from simple systems of entities of their immediate personal experience (e.g. users, computers, cables, modems) to more complete systems of detailed and elaborate descriptions. Although these students had been taught about internet before the current research, few of them managed to provide acceptable representations from a scientific point of view. Results that have been reported by Papastergiou (2005) from a sample of students at the beginning of the Informatics Curriculum, suggested that students form simplistic, utilitarian rather than structural models of the internet, which would provide them with an adequate explanatory system of what internet actually is and the process underlying its use. Although any direct association of the results of the above studies to the VRep of the textbooks is beyond discussion, one can identify some kind of influence. For example, the sign of a cloud, used as a symbolic representation of the Internet in the textbooks, appears in students' drawings as well (Kollara et al. 2000) and is used without a clear understanding of its meaning. Also, although school textbooks involve representations of the architecture of different types of networks, which seems to affect students' drawings of the Internet up to a degree, the small number of students, 7 out of 340, who provided a drawing of the Internet as a network of computer networks (Papastergiou 2005) may be due to the absence of such a type of representation in the school textbook.

VRep and other visualization tools for conceptualizing the Internet can play a large role in students' understanding as they provide images of a world which they are unable to see. Increased access to networked technologies together with students' deeper understanding of their nature and functionality mean that there is the potential for a significant extension of the learners' capabilities, among which is a more informed use of various Internet services.

It seems that two factors are important for the teaching and learning processes: students' experiences and ways of thinking about the Internet, and the selection of appropriate teaching materials and learning activities for its structure, functioning and uses. Research evidence in these fields is limited and different aspects of the Internet and different approaches have to be adopted for revealing this multifaceted issue.

2 The role of visual representations

Technological innovations have opened up new worlds for students to explore. Yet, as the development of new scientific technologies accelerates, research into the use of these technologies in the school curriculum lags (Webb 2002; Yan 2006; Papastergiou 2005). The fact noticed by Pozzer and Roth, (2003) that high school science is dominated by textbook-oriented approaches to teaching and learning is met in Computer education, at least in Greece, as well. Therefore, the quality of curriculum materials and particularly textbooks is very important and more research has to be undertaken on

this issue (Good 1993). Given the prominent role of visual representations in scientific communication and in the learning of science, it is surprising that their roles have not been addressed more systematically and abundantly in scholarly discussions (Cheng and Gilbert 2007). Kress and van Leeuwen (1996) ascribe this negligence to the overt focus on verbal languages in society, which has led to the devaluation of the benefits offered by the visual mode of communication.

Mental representations of scientific and technological entities have been accepted as being of major importance in the teaching-learning process that is affected by features such as visual resources (e.g. pictures, diagrams, photographs, and tables), which come to dominate the mental representation due to their salience (Crisp and Sweiry 2006). In the study by Crisp and Sweiry (2006), it is reported that in some cases the visuals can increase the likelihood of students making unhelpful interpretations of an exam question and that students may be led astray by an element in a visual resource that was not intended to be important. The issue of using colours as symbolic representations e.g. of 'hot' and 'cold' entities (in the context of school physics) has also been explored and it was found that some students' contradictions are reinforced by the coloured images in textbooks which also frequently leads to misconceptions and to the remembering of facts and interpretations that are based on context and not on scientific knowledge (Carvalho and Sousa 2006).

The importance of teachers' strategies in dealing with such kinds of difficulties is also an important factor. The meaning of the way that scientific knowledge is presented in school chemistry textbooks and is used by teachers is investigated by Furió-Mas et al. (2005), who claim that the existence of certain views of science either in textbooks or among teachers themselves contribute to an impoverished image of chemistry. Designing effective instructional materials is also important for the impact of multimedia on a learner's performance and satisfaction and one of the key issues is the selection, integration and fitness of appropriate media, such as text, picture, audio, animation and video (Sun and Cheng 2007). Multiple representations may serve to complement one another with regard to information or processes, to constrain the interpretation of one another, or to construct new connections between one another (Tsui and Treagust 2003). "They require coherence formation; learners must create referential connections between corresponding features of different representations" (Cook 2006, p.1078). Animations, on the other hand, by their nature, present multiple images over time which allow viewers to perceive phenomena much as they would in the physical world; an example of the trend to use highly illustrated materials like animations has been reported by Lowe (2003). Aspects of how computerized models can serve as a vehicle for students to generate mental images have been explored in the study by Wu et al. (2001). They suggest that technological visualizing tools can facilitate students' skills in making translations among different types of representations of invisible and abstract chemical entities, building molecular models and transforming two-dimensional structures into three-dimensional ones. Similarly, the value of visual representations in textbooks increases when the content refers to entities that cannot be experienced directly, in other words processes or entities of very small or very big scale which it is not usually possible to see, and about which students' thinking cannot rely on sensory information. Questions regarding what kind of VRep authors include in school textbooks, and what ideas these VRep introduce in the classroom agenda for

each conceptual field, play a great role in today's visual world. By examining how textbooks attempt to create visual representation of the inherently abstract Internet phenomenon, we may get some insight into how a 'material culture', a culture of concrete Internet representations, is constructed among students and what improvements in teaching and learning could be undertaken.

3 Representations of the Internet in school textbooks

3.1 ICT in the Greek curriculum

Information and Communication Technology (ICT) in the Greek education system meant initially the introduction of ICT as a new subject matter into the Curriculum. During the pilot phase, this initiative introduced ICT into 22 lower secondary schools (1984–87) and into 8 technical and vocational upper secondary schools (1984–86) (Panagiotakopoulos 1998). This techno-centered approach (Makrakis 1988) has been established since then, and the subject matter of ICT is now taught in all kinds and at all levels of secondary schools. It was only after 1990 that an integrated approach for ICT was suggested. Although different actions have been taken in this direction and the debate is continuing, teaching and learning across curriculum is not yet broadly supported by ICT. Teaching and learning of ICT is mainly based on textbooks and partially on practical computer experience. The main aim is to provide students with basic skills and knowledge about the computers, the various sub-units and functions, as well as the services, the algorithms and programming. This involves some understanding of the workings of information technology as a subject, which we could say aims to develop students' computer literacy.

An important domain of ICT taught in Greek secondary schools is the Internet and its functionality. As a whole structure, this entity is not part of students' everyday experience and also a lot of the functioning is not apparent, but students may use one or more of the services the Internet offers. Learning develops when a student hears in everyday life about this huge network of networks, when he/she listens to a teacher's description, when he/she studies the book, when he/she uses it, but also when he/she looks at visual material. Deciding what sort of visual representation is necessary and adequate to usefully depict a terrain is the major challenge in cartography. The challenge grows when the terrain being mapped is less stable and less permanent than mountain ranges and rivers. Disagreeing about how to map physical reality is one thing; disagreeing about whether the objects that are being mapped and represented are physical at all generates a higher level of ontological confusion. This is the conundrum that one faces when attempting to represent the Internet visually, since it is a rather ethereal "thing" (King 2006).

4 Research goals

We attempt to recover the natural scientific practices related to reading visual representations of the Internet that are embedded in textual materials in the Greek secondary educational reality. We also attempt to relate our reading of these visual

representations to the students' reading. So, in this paper, we ask the following questions:

- What kind of visual representations are commonly used to portray the Internet in the school textbooks?
- What characteristics do visual representations of the Internet present and what purpose do they serve?
- How do students label two specific representations contained in ICT textbooks?
- What is students' reading of these two representations and what do they show to us?

By examining textbooks practices in selecting or constructing representations that attempt to portray the Internet realistically, in a way that is 'accurate' or 'authentic' and by exploring how 'sensible pictures' these can be for students, we may get some insight into the pivotal roles and functions of representation practices in ICT and school learning.

5 Methodology

In this study we adopted two complementary approaches in exploring the role of VRep of Internet in school learning. First, we focus on teaching materials and we analyze the VRep for the Internet of secondary school textbooks of Informatics (Part A). Second, we focus on what students see when they look at a VRep, related to the Internet, and we explore their interpretations for two specific VRep of the Internet (Part B).

5.1 Part A: The corpus of data and the method of analysis

The corpus of data gathered initially consists of all the visual representations related to aspects of the Internet involved in two school textbooks used, one for lower secondary school (year 3) (Damianakis et al. 2006) and the other for the upper secondary school (year 4) (Giakoumakis et al. 2005). The second one is taught in both General and Technical education schools. The two books are written by two different groups of authors, who are scientists, specialists in ICT, or teachers of ICT. The analysis of another new book that was published near the end of our study (Arapoglou et al. 2006), planned to be introduced into the curriculum in the future, was also added.

The visual representations were analyzed by employing the approach of inductive category development of qualitative content analysis (Mayring 2000). In this approach it is of central interest to develop the aspects of interpretation, the categories, as near as possible to the material, to formulate them in terms of the content of the material under analysis. Although we share Kress and van Leeuwen' s (1996) position for composite or multimodal text analysis, we will proceed by analyzing not the cultural values/practices, but the cognitive elements. Our unit of analysis, namely, the fragment that is categorized each time, is each visual representation with the accompanying label in relation also to the relevant text.

The produced categorization, in the form of a systemic network (Bliss et al. 1983), was validated by three researchers, of whom two were specialists in ICT and one was a science educator. Each researcher applied the scheme of categories to the VRep of the textbooks independently and the small alterations needed were identified, until a degree of certainty was obtained of its validity.

5.2 Part B: Students' reading of the VRep of the Internet

Visual representations are essential in communicating ideas in classrooms; however, the design of such representations is not always beneficial for learners. Such considerations have been investigated placing emphasis not only on the cognitive architecture (working memory capacity, cognitive load of representation), but on students' individual differences and especially their prior knowledge (Cook 2006). Most of the research in this field studies the students' use of representations in conjunction with textual information (Mayer and Anderson 1992; Winn 1991). The co-deployment of VRep and written language is a very important feature in learning materials, but one could also consider whether a VRep can at first hand be effective in helping readers to identify the main idea that was intended to be portrayed and envision the new information. In this study, we aimed to explore the plain visual power of VRep, that means to what extent VRep on their own can create the expected experiences for students and what kind of aspects of VRep attract students' attention. Our analysis is based on the labels that the students themselves add to the representations, without reading the surrounding text.

Eight VRep from the ICT textbook of lower secondary school have been chosen and a three-page worksheet has been produced. The VRep were presented in exactly the same way (colour, size) as in the textbook. Blank spaces were left near each representation, where the students were asked to write a label describing the content and the functions that are represented. Students of 4th and 5th year of four schools of General and Technical education participated and spent about an hour working on the tasks. The provided labels of 89 students have been systematically analyzed, although we have collected more data for some of the VRep. All students had been taught the relevant curriculum ideas and had used the specific textbook where the VRep were included. This means that students had some kind of experience with these VRep. It is beyond the scope of this paper to proceed with the analysis of all the VRep. However, we consider that evidence from the students' experiences with the VRep, is complementary to the rationale developed in the first part of this work. So, findings from students' labels for the two of these VRep are discussed in this study. The two VRep can be seen in Figs. 6, 8.

5.3 Part A: The VRep of Internet in school textbooks

5.3.1 Categories of analysis

Each representation is initially analyzed in terms of the VRep itself and in terms of its relevance to the text and entities referred to. So, each VRep is characterized according to what type it is, and to the existence or not of a caption. The VRep's relevance to the text and the entities referred to is examined on a conceptual,

functional and spatial basis. The categories which emerged through the overall analysis are presented in the systemic network of Fig. 1.

One dimension in the analysis of VRep is related to the characteristics of the VRep itself: its *type,* and the existence of a *caption*. The first category is further analyzed in terms of how Internet depictions are graphically portrayed and in terms of their relationship with reality. So, a VRep is considered a *schematic representation*, when different entities or functions are portrayed diagrammatically but in a rather abstract way, probably in an attempt to have a more scientific sense. In this case, entities or a number of entities are represented by symbols, such as lines or rectangles, or even drawings of commonly used prototypic forms. When the diagrammatic representation is a composition of drawn entities, e.g. drawings of computers, then the VRep is placed in a different category, the *construction with entities*. The drawings here are more accurate depictions of the real entities, which are preferred for the representation of the constructions, instead of real photographs. The category of *snap-shots* is created by the VRep which capture instances of computer screens during the corresponding specific computer services. VRep with rather allegorical depictions of the Internet, mostly comics, fall into the category of *sketch—comic*. In this category, sketches that do not have a comical sense usually represent the target ideas in a looser and freer expression.

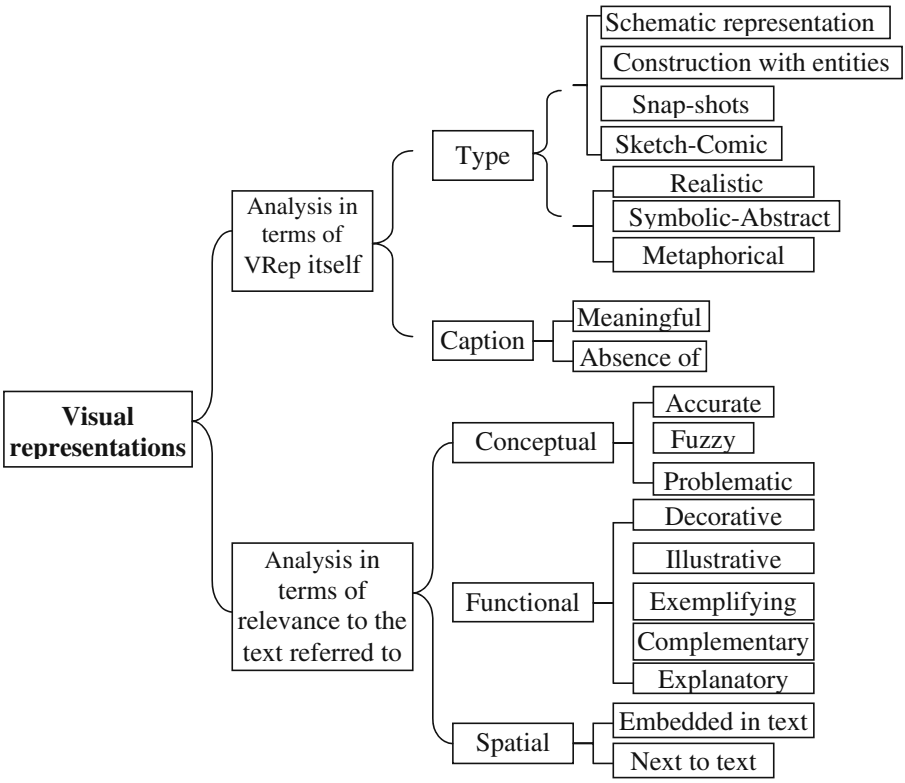

Fig. 1 Systemic network for the categories of visual representations of the Internet in school textbooks

It is worth noticing that the chapters about the Internet in both textbooks do not contain any photographs. One reason for this may be the nature and the scale of the relevant systems and the entities which, as not all being visible, are beyond photographic limits or possibilities.

In terms of their relationship with reality, VRep can be also classified as *realistic*, when they try to describe the different aspects of the Internet in a more detailed way, as *metaphorical*, when they connote or symbolize meanings over what they represent, and as *abstract—symbolic*, when the VRep aims to project the ideas in a rather scientific approach.

Captions play an important role in the understanding of the VRep, so its *existence* is examined and characterized as either *meaningful* or as *irrelevant*.

A second dimension in the analysis of VRep is related to the *relevance* of the story described in each VRep and the corresponding text or the entities it is supposed to exhibit, and three categories have been employed: the *conceptual*, the *functional* and the *spatial*. The *conceptual* relevance is examined in terms of *accurateness*, *fuzziness* or *problematic aspects* with reference to the scientific meanings of the represented entities. The *functional* relevance expresses how each VRep stands for a learner's reading. As *decorative* are counted the ones that are not intended to play a role in learning, but to make the page more beautiful or interesting, or give only a general aesthetic sense or feeling of the textual spirit. As *illustrative* can be characterized the VRep, that provide simple representations of entities discussed in the text, without adding meaning or information in the textual reference. Sometimes, an illustrative VRep can prove to be more useful than definitions for giving the meanings of words. *Exemplifying* VRep are considered the VRep that are complete examples or a variety of instances related to the entities or concepts the written language refers to. VRep function as *complementary* when they provide information not included and described explicitly in the linguistic component. Sometimes they highlight the most important points addressed in the text or extend the information of the text in richness or in new fields, thus contributing to the completion of the intended new knowledge. In the category of *explanatory* VRep fall the ones that assist the text and provide new aspects of information necessary to make the explanatory, conceptual or technical mechanisms under consideration, clearer.

The *spatial* placement refers to the position of the VRep on the page. So, a VRep can be *embedded in the text* or in a separate column *next to the text*.

Some examples of the school textbooks' VRep are discussed in terms of the scheme of our categories. In Fig. 2 a VRep categorized as a snap-shot is presented. It is also characterized as realistic and accurate. It is followed by a meaningful caption, it functions as an example for the main text and it is placed next to the text.

The VRep presented in Fig. 3 is a characteristic example of the category of sketches which depicts the World Wide Web. It is symbolic and its intention is to create a sense of the WWW by combining the symbol 'WWW' with two computers positioned on opposite sides of the globe and connected by a curved line with two arrowheads. This synthesis is taken as 'fuzzy', as it shows a rather confusing image. It does not include a representation either of the system of multiple connections which is an important aspect of WWW, or of its other important feature, its complexity. It has no caption and is placed next to the text. It can be considered more as decorative, as it does not really play a role in learning about the WWW.

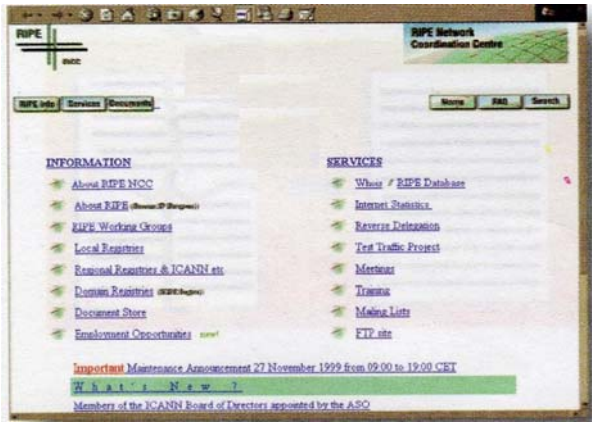

Fig. 2 An example of a 'snap-shot'

The VRep presented in Fig. 4 refers to the teaching of the concept of Internet Service Provider (ISP). It is placed next to the text and has no caption. It falls into the category 'construction with entities'. It is characterized as 'abstract', since it does not depict any details or features of what an ISP really is or looks like. Although it can be considered as 'explanatory' as its intention appears to be the explanation of the role of ISP, it seems to be rather problematic because it does not really support the reader's understanding of ISP. For example, someone could relate ISP to only two computers. The symbol, a type of box, representing ISP seems like a small apparatus connecting two users. Because also of this symbol's small size, the VRep does not give the real meaning of ISP as an organization with a powerful computer to which a number of other computers can possibly be connected.

Fig. 3 An example of a 'sketch'

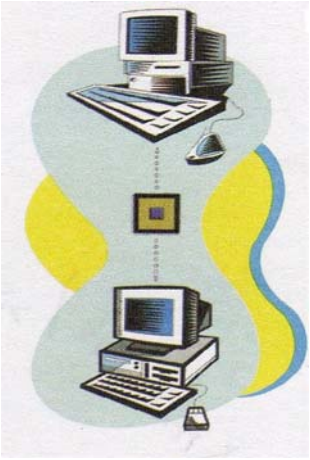

Fig. 4 An example of the category 'construction with entities'

In Fig. 5 a characteristic example of the VRep category 'schematic representation' is presented. It is realistic, as it gives a sense of the real situation it stands for, and it is accompanied by a meaningful caption. It is embedded in the text and can be considered as accurate. It functions as a complementary learning tool, as it provides more information about the role and the links of an ISP.

5.3.2 Findings

Table 1 presents the frequencies of categories of VRep that are met in secondary textbooks. As is shown, the category 'sketch-comics' seems to be the most usual

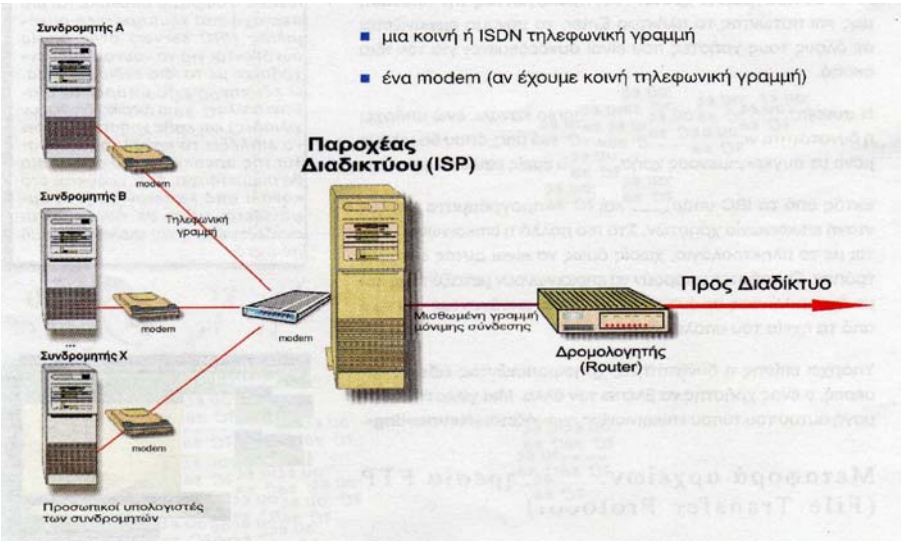

Fig. 5 An example of VRep belonging to the category 'schematic representation'

Table 1 Frequencies of categories of vrep met in secondary textbooks

Categories		Percentage %		
School textbook		3rd grade	4rth grade	2nd grade (new book)
Type	Schematic representation	8.0	10.5	21.1
	Construction with entities	16.0	0.0	0.0
	Snap-shots	32.0	78.9	42.1
	Sketch-Comic	44.0	10,5	36.8
	Realistic	36.0	89.5	47.4
	Abstract—Symbolic	24.0	5.3	10.5
	Metaphorical	40.0	5.3	42.1
Conceptual relevance	Accurate	48.0	73.7	47.4
	Fuzzy	44.0	21.0	52.6
	Problematic	8.0	5.3	0.0
Functional relevance	Decorative	36.0	5.3	26.3
	Illustrative	12.0	5.3	15.8
	Exemplifying	40.0	73.7	21.1
	Complementary	4.0	0.0	5.3
	Explanatory	8.0	15.8	31.6
Caption	Meaningful	40.0	52.6	73.7
	Absence of	60.0	47.4	26.3
Spatial placement	Embedded in text	12.0	100.0	42.1
	Next to text	88.0	0.0	57.9

VRep in secondary ICT textbooks of year 3. In the same book one third of VRep are ‘snap-shots’, while in the textbook of year 4, the majority of VRep are ‘snap-shots’. This is the reason why the majority of VRep in this book are characterized as ‘realistic’, while more than half of VRep in the textbook of year 3 fall into the categories of ‘abstract-symbolic’ and ‘metaphorical’ VRep. The textbook of year 4 appears to contain more ‘accurate’ VRep than the textbook of year 3, in which almost half of them seem to be ‘fuzzy’, while some of them in both textbooks can be characterized as ‘problematic’.

Concerning their ‘functional relevance’ to the text, over one third of VRep in the textbook of year 3, are ‘decorative’, two fifth are ‘exemplifying’, and the rest are ‘illustrative’, ‘complementary’ and ‘explanatory’. In the textbook of year 4, most of the VRep are ‘exemplifying’ while only some of them are ‘decorative’ and ‘illustrative’. In the same book, less than one fifth of the VRep can be characterized as ‘explanatory’.

It is worth noticing that in both textbooks there are very few ‘complementary’ and ‘explanatory’ VRep. Taking into account that these kinds of VRep are considered the most important ones in terms of learning goals, the value of VRep as essential learning tools is doubted. Nor are learning goals supported by the captions, as we notice that in more than half of VRep of the textbook of year 3 and about half of those of year 4 captions are absent. The characterization of a caption as meaningful has to do with the cooperation between the representation and the caption only.

Regarding their spatial placement, we found that different practices exist. In the book of year 4, all VRep are embedded in the text. Half of them are placed in-between the text related to the VRep, while half of them follow the relevant text. In the book of year 3, the main practice is to divide the page by a vertical axis which separates the text from a column, where the majority of VRep are placed. Some of

the VRep, however, exist inside the vertical fluency of the text. Only a few of them are placed above the relevant text or in-between the relevant text or follow it.

While this study was being carried out, a new school textbook appeared which is planned to be taught in the 2nd grade of the secondary school and is probably going to be used in the future. We considered it interesting to apply our scheme of categories to the chapters of the textbook about Internet as well. All VRep in these chapters fitted well in the categories of the systemic network. The results have been included in Table 1, in the third column. We notice that most VRep are snap-shots, more than 30% fall into the category of 'sketch-comic' and about 20% fall into the category of 'schematic representation'. Only half of them can be considered as accurate, while half of them are fuzzy. In terms of their functional relevance most of the VRep are characterized as explanatory to the corresponding text, more than one fourth as decorative, one fifth as exemplifying, while the rest of them as illustrative and complementary. In more than one forth of the cases VRep are not followed by a caption. Usually they are placed next to the text, while almost half of them are embedded in the text and most of them are found under the relevant analysis. Although we see that there are no problematic VRep included in this new textbook, a lot of them can be characterized as fuzzy and the philosophy and the role of the VRep are similar to the two other textbooks analyzed.

5.4 Part B: Students' experiences with VRep

5.4.1 The VRep of Internet viruses

The first VRep (Fig. 6) refers to the internet viruses which travel and shows how viruses infect personal computers during users' web surfing. It is placed next to the text and it is a characteristic example of the 'comic-sketch' category. It has a metaphorical sense and is characterized as fuzzy. In terms of learning, this VRep's

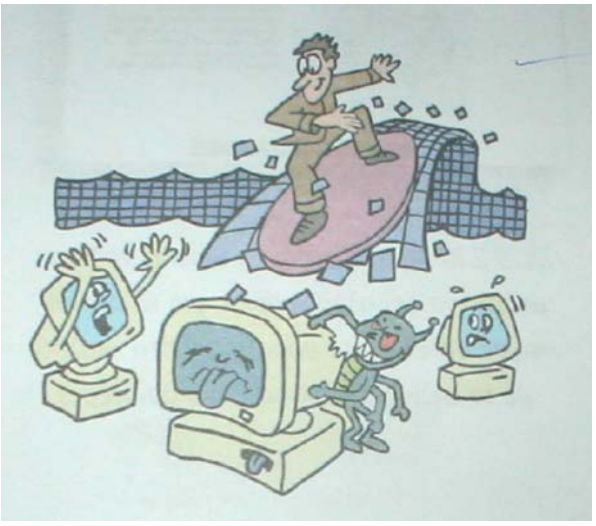

Fig. 6 The VRep of Internet viruses

function has an illustrative role. It is not accompanied by a caption. The texts of the students' labels were analyzed and the systemic network that has been produced is presented in Fig. 7.

Table 2 shows the percentages of students' labels that fall into the main categories of the network. The analysis showed that most of the students have responded to this task. A small group of them did not manage to describe the VRep in terms of Internet viruses or even in terms of the VRep content. These students *referred to ICT ideas in general*. A characteristic example is the following: "Illegal surfing on the Internet can cause damage to the computers".

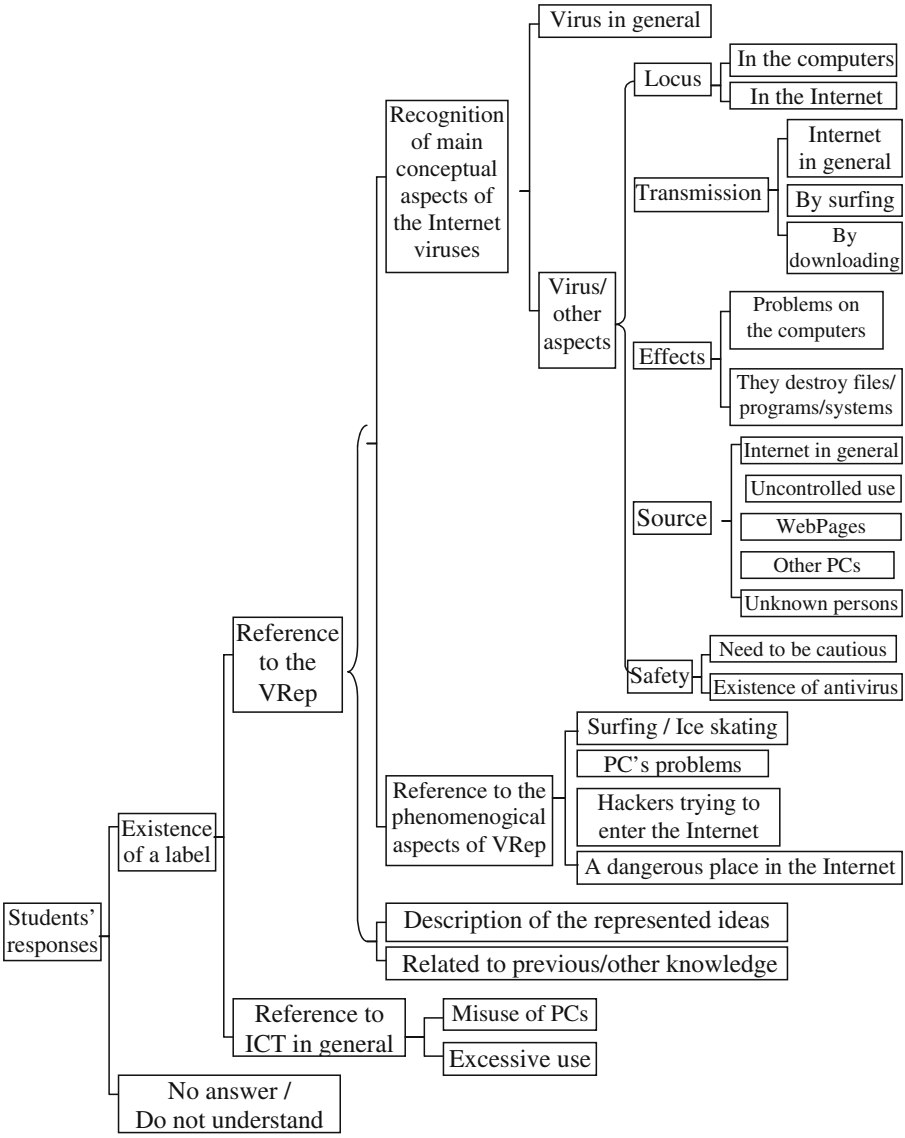

Fig. 7 Systemic network for students' answers about the VRep of Internet viruses

Table 2 Percentages of aspects of descriptions for the vrep of internet viruses

Aspects of answers					Percentage %
		Recognition of main conceptual aspects of the Internet viruses	Virus in general		15.7±3.9[a]
			Virus/other aspects	Locus	40.4±5.2[a]
				Transmission	29.2±4.8[a]
				Effects	14.6±3.8[a]
	Reference to the VRep			Source	13.5±3.6[a]
Existence of a label				Safety	13.5±3.6[a]
		Reference to the phenomenogical aspects of VRep			10.1±3.2[a]
		Description of the represented ideas			71.9±4.8[a]
		Related to previous/ other knowledge			5.6±2.5[a]
	Reference to ICT in general				5.6±2.5[a]
No answer / Do not understand					16.8±4.0[a]

[a] The values after the ± sign are the standard error

Most of them, however, gave labels with *reference to the VRep*. One tenth of those students described the VRep in terms of the *phenomenological aspects of VRep*. Labels like, "Many, many hours surfing on the Internet" or "Computers become tired when children surf so much", are considered to be affected by exactly what is represented in the VRep, while the intended meaning of the VRep cannot become apparent to the students. Another characteristic example is the following: "He is surfing on his computer, but the others (computers) are old and they are not able to do it (surfing)". The student's attention in this case is attracted by the "faces" of the computers that are frowning, but also by the absence of a person to one computer correspondence. The students' reading is purely phenomenological.

Quite a large percentage (about 70%), however, showed *recognition of the main conceptual aspects of the Internet viruses* VRep. So, they managed to label this VRep in terms of the virus concept. They mainly described the VRep on the basis of represented ideas, but a small number used *previous knowledge related to* the VRep, not necessarily explicitly expressed in the VRep. This last category includes answers like the one that follows: "Computers are affected by a virus from the Internet and it seems that they cannot be protected because they do not have any Antivirus".

From the group of students that recognized the main idea of the VRep, some of them referred to *viruses in general,* while most of them referred to viruses and *other relevant conceptual aspects*. In their descriptions, aspects related to viruses, like their *locus*, the *way and mean of transmission*, their *effects*, their *source* and the *safety* issue can be identified. Their descriptions may refer to one or more of these aspects, which also reveal their thinking about Internet viruses initiating certainly from this specific VRep. So, students talk about viruses as found in the Internet, or in the computers, as being transmitted by surfing or by downloading, leading to problems

like destruction or overloading the computer, or files and programs' destruction, having their origins in WebPages, in other PCs, or unknown persons. Students also see viruses developing from uncontrolled use of computers. A number of students describing the VRep referred to safety issues, with warnings like "Be protected from viruses", or the need for antivirus.

Labels were also analyzed in terms of the relationship of their descriptions to what is actually represented in the VRep. Although the majority described what they actually experienced with the VRep, a small percentage used other relevant ideas or previous knowledge not necessarily inferred from the VRep. References to the need for antivirus or to illegal surfing cannot be considered as represented in this specific VRep, but students labeled it using ideas they had in their conceptual field and which were considered relevant to the represented entities.

Two examples of more complete labels are the following: "Through Internet someone from another computer can infect yours with a virus. This can destroy all your programs", "Viruses transmitted to our computer from other computers through our navigation in the Internet".

5.5 The VRep of packets' transmission

The second VRep (Fig. 8) refers to the packets' transmission. In the textbook, it is placed next to the text and is accompanied by a caption that can be characterized as meaningful in terms of the content of the representation itself. The caption describes the VRep as following: "*In order for the page of a message to be transmitted via Internet, it is separated into pieces, called* '*packets*'." It can be characterized as 'schematic representation' and has a metaphorical meaning. It has also been characterized as fuzzy and aims to give an example of the situation being described. The texts of the labels were analyzed and the systemic network produced is presented in Fig. 9. Table 3 shows the percentages of students' labels that fall into the main categories of the network.

The majority of students did not manage to give a label. About one fifth of them were influenced by *phenomenological aspects of the VRep,* which are *irrelevant to the ICT* context. Most of them saw the represented entities as pages, while a few named them as "ventilators" or as "air-conditioning". It is worth noticing that these were students of mechanical technology studying in a technical secondary school. What these students saw in the VRep was related to their own experiences.

Another group's labels referred to *phenomenological aspects of the VRep*, which were considered as more *relevant to the ICT* context, as pages, files, documents or

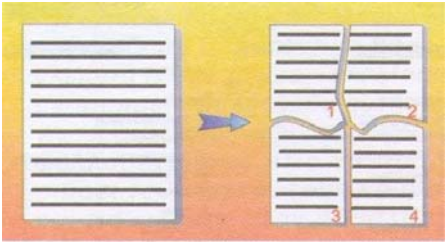

Fig. 8 The VRep of packets' transmission

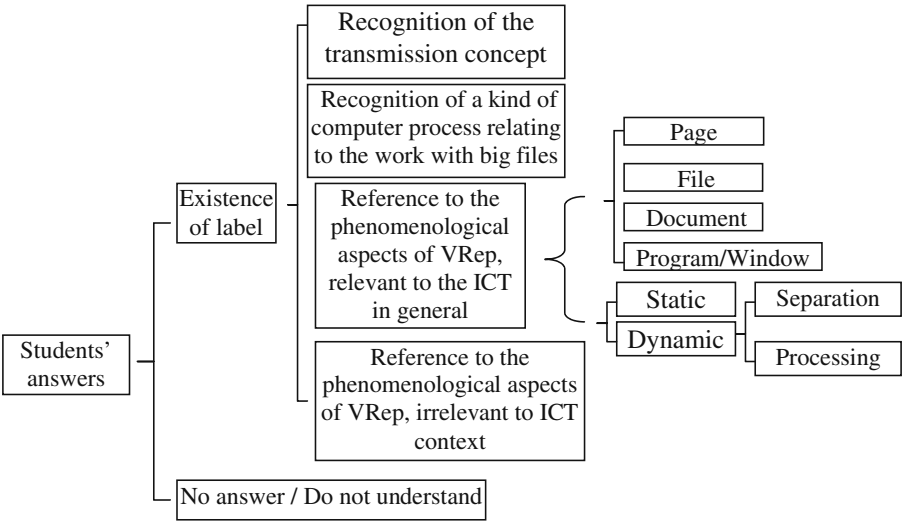

Fig. 9 Systemic network for students' answers about the VRep of packets' transmission

windows. These labels were further analyzed according to whether they had a static or a dynamic character. As dynamic are considered the labels mentioning either separation, e.g. "a page that has separated into four parts" or a kind of processing, e.g. "This picture shows a program for word processing. This may be the Microsoft word".

Another small group of labels recognize in this label a kind of computer process relating to the facilitation of a big load of work either in terms of the computer function, or in terms of the user. Two characteristic examples of this category are the following: "The separation of a document into more parts after being saved", "Breaking up of files into smaller parts for easier management and manipulation".

Lastly, two labels revealed a kind of appreciation of the VRep meaning that is closer to the one intended, the Packets' transmission: "We understand that we can download a file that consists of smaller ones and to download them for getting

Table 3 Percentages of aspects of descriptions for the vrep of packets' transmission

Aspects of answers			Percentage %
Existence of a label	Recognition of the transmission concept		2.2±1.6[a]
	Recognition of a kind of computer process relating to the work with big files		8.9±3.0[a]
	Reference to the phenomenological aspects of VRep, relevant to the ICT in general	Page	3.4±1.9[a]
		File	4.5±2.2[a]
		Document	16.8±4.0[a]
		Program/Window	2.2±1.6[a]
		Static	7.9±2.9[a]
		Dynamic	11.2±3.4[a]
	Reference to the phenomenological aspects of VRep, irrelevant to ICT		21.3±4.4[a]
No answer / Do not understand			53.9±5.3[a]

[a] The values after the ± sign are the standard error

connected", "The image shows us that through the Internet we can cut different things into pieces in order to download them more easily".

6 Conclusions—teaching implications

The findings presented here support the need to investigate the role of Visual Representations in teaching and learning and especially the teaching and learning of curriculum topics, like the Internet, which are beyond students' immediate experience. The first part of this work focused on how the Internet is represented in three secondary school textbooks. It was found that the main features and services of the Internet are presented mainly through snap-shots and sketch-comics. Snap-shots are more popular in the textbook of 4th grade, while sketch-comics in that of 3rd grade, probably as the former are considered more scientific and the latter more simplistic. This is also supported by the second kind of categorization, according to which it was found that the majority of VRep in the textbook of 4th grade can be considered realistic, while more abstract-symbolic and metaphorical VRep exist in the textbook of the 3rd grade.

In terms of snap-shots, it seems that they highlight the real and practical face of the Internet and are taken to stand as photographs capturing computer screens, while the main purpose they serve seems to be students' guidance through the steps of a procedure. However, it is not certain that this can be achieved. For example, the chapter about the Internet, in an attempt to provide students with an opportunity to understand electronic commerce, involves a specific webpage where software about the golden moments of Greek athletics is advertised, ordered and bought. Such an approach places the students in the role of the final user and neglects to focus on and make apparent to them the subsequent procedure. On the other hand, sketch-comics can pass a powerful message to the reader as they appeal to the readers" analogical thinking, but usually a lot of interesting and essential aspects of the concepts get lost in superficial meaning.

The fact that the entities and functions related to Internet have an abstract and invisible nature may explain the differentiation identified within the field of high school biology textbooks, where the ontology of the entities studied is of a different nature and where it was found that 17 photographs on every 20 pages are included (Roth et al. 1999).

It is worth noticing that of the VRep examined, in the two of the textbooks, less than half can be characterized as accurate, the rest being fuzzy, some of them even problematic, which could possibly mislead students. The practice of textbooks to neglect to use captions or other textual information on the VRep, to explain or guide the reader or learner through the main features of the represented entities or processes, is also surprising, as this has been acknowledged as very important for learning. This, together with the fact that VRep have mostly either a decorative, illustrative or exemplifying function, highlights the important issue of selection of fruitful representations.

This is also supported by evidence from the second part of this work on how students experience two of these VRep, when used without the textual supplement. In an effort to generalize the findings from the two representations, we can say that students' conceptualisations follow similar paths: The first level is characterised by

students who pay attention only to the general phenomenology losing sight of the context of ICT, where the VRep is placed. At the second level students' attention is attracted by the context of ICT in general, but without discerning the main idea conveyed. The third level is identified when phenomenological aspects, related up to a degree to the main idea aimed to be displayed, attract students' attention, while the fourth level is identified when conceptual aspects of the displayed main idea are recognized. It is the fifth level where we finally meet students' recognition of the content and the conceptual meaning of the VRep. However, comparing the learning function of the two images, the representation of virus transmission seems to have a greater impact on students' appropriate conceptualizations. Although their descriptions were not complete, the majority recognized the main idea. On the contrary, only 2% of the students recognized the main idea in the case of packets' transmission and only 9% of them described a procedure that may be considered as similar. One way to interpret this fact is to focus on the conceptual aspects of the represented ideas. The first VRep aims to introduce and illustrate the idea of virus transmission and its locus, while the second refers to the understanding of the basic mechanism of a process that is a more demanding task. A second interpretation could be given in terms of the representational aspects of the two VRep. While both representations have a metaphorical character, in the second one the metaphor is not apparent. Without a caption it functions as a representation of a reality which is far from the actual field aimed to represent. This VRep on its own seems to be inappropriate for supporting students' learning of packets' transmission. Even with the caption, however, it would not be more helpful as the separation of the page, to which it refers, may mislead the reader; it seems to be related more to a macroscopic process than to a binary one through channels of transmission. Moreover the important idea of the sequential character in the data transfer process is encrypted.

It could be argued that the rationale of the textbook does not follow a specific direction in selecting the VRep. The traditional approach pays more attention to what is written in textbooks than what is represented. On the other hand, the VRep from the reader's point of view is another important issue that is neglected; the phenomenology of the representation imposes certain features and consequent ideas on students' reading and interpretations which the authors or the teachers would never have thought about. A similar phenomenon in a different context of science and mathematics, has been reported by Bell and Janvier (1981) where they describe 'pictorial distractions': graphs are judged by visually salient clues, regardless of the underlying meanings. Pozzer-Ardenghi and Roth's analysis (2004) showed that one of the major functions of photographs in Biology is to capture readers' attention and found that students interviewed noticed and commented on the photographs before referring to the texts. They claim that it is important to be attentive to intrinsic characteristics of photographs, as for example its background and framing.

Research evidence seems to support a phenomenographic approach to learning (Marton and Booth 1997), where a learner experience a phenomenon (a learning object visually represented in our case) and gain knowledge about it through an ongoing exploration of the phenomenon as described by others. Descriptions of the phenomenon, then, are affected by the level of awareness of its structural and referential aspects and "we can experience something as something thanks to the two basic capabilities we are equipped with and the constraints which limit the

capabilities: (a) we can discern entities and aspects, and (b) we can be focally aware of a few entities or aspects simultaneously." (Marton and Booth 1997, p.123). In our case, these seem to be crucial, as what actually differentiates the students' labels is their ability to discern entities and aspects involved in the VRep and also to be focally aware of the entities and aspects of the two analogical fields (sea surfing and internet navigation) involved. This last point is related to the poor results with the packets' transmission of VRep, which can be characterized by the 'appresentation' of the ICT context (Marton and Booth 1997, p.99).

Our research raises questions about the invention or development of possible representations of the Internet that would be worth a thousand words. Three directions have to be further exploited: the inquiry of fruitful representations of the Internet, the students' responses to them, and teachers' use of the VRep in the classrooms. The scientific community also has good reasons to face the issue of accurate representations that could better represent what is going on in this huge space, its topology and routing (Gast and Barford 2004; Yegenoglou et al. 2000). A huge variety of visual representations of the Internet have been produced and a typology has been suggested (King 2006), artistic representations, Network Topology maps, Geographical maps, hierarchical maps, Logico-Spatial representations, pseudo-physical representations, etc. There are also research groups like the Cooperative Association for Internet Analysis (CAIDA) that is developing and deploying tools to collect, analyze and visualize data on connectivity and performance across a large proportion of the Internet (Claffy et al. 1999). Depictions like Internet 'Tomography' seem to enrich our knowledge system and provide us with images that cannot be acquired in any other way.

But how and why do students interpret a representation in a certain way? Let us take the case of VRep of packets' transmission (Fig. 8). What aspects of this procedure are actually presented there? The authors' intention seems to be the selection of an image familiar to students. So, its content is limited to their experience with documents, introducing only the idea that in order for a document to be transmitted it has to be broken and separated into pieces of standard size. The important aspect of packets' transmission and its sequential flow is absent. Such a representation could be

Fig. 10 A data packet being loaded

combined with another, like the one in Fig. 10 (Dodge 2001). This depicts the binary data flow and the standard size of the package clearly. Nevertheless, there is still a point that cannot be considered as precise; the way that the binary data flow and are loaded is not clarified. This means that for reasons of accuracy, binary data should be presented as falling in a serial way and not as all mixed up.

Of course, as Stern and Roseman (2004) argue no single representation can be completely correct; a variety of representations of the same idea, each representing different aspects of the idea, might contribute to a more complete understanding. Moreover, a process involves many more aspects necessary for a complete frame of understanding and a number of questions have to be answered. Where does this happen? What are the reasons for this procedure? Why can't the data be transferred in a continuous, serial way? How are the packets actually transmitted? What happens at the destination? Such matters should be included in the textual information, and used for framing the specific Vrep selected. Data transmission is an essential part of the functions taking place, and as happens with many other entities and processes of the internet, its workings, on the one hand, are internal and cannot be seen and on the other are parts of a larger system. These two features of the packets' transmission and other similar features for other learning cases have to be taken seriously into account by school textbook authors.

Vision is central to our biological and socio-cultural being. As biological and socio-cultural beings, we are encouraged and aspire to 'see' not only what comes 'within sight', but also what we are unable to see (Arcavi 2003). Thus, one way of characterizing visualization and its importance, both as a 'noun'—the product, the visual image—and as a 'verb'—the process, the activity—(Bishop 1989), is that as McCormick et al. (1987) described it 'visualization offers a method of seeing the unseen'. Such a perspective can be taken into account for the development of appropriate teaching materials and visual means that could help transcend the limitations of the mind, and also can lead the planning of appropriate classroom practices and well focused teachers' actions. Teachers' interventions relating to different kinds of representations and oral explanations supplementary to the visual and textual information can be undertaken. Especially in the case of the teaching of the Internet, the systemic nature of this huge internet has to accompany the topics under discussion. The teaching materials and teaching style need to be adapted to the specific characteristics of the domain to be taught, in our case the Internet. It is urgent and fundamental, that all involved in the learning adventure—authors, educators and teachers—should be thoughtful and flexible, in order to produce learning situations and educational technology appropriately adaptable to the ontological history of this web-globe. Visualization of the Internet can provide images of it that will help students to be knowledgeable persons and critical users of the experience offered by this new world wide net.

References

AAAS—Project (2006). *Identifying Curriculum Materials for Science Literacy:* Project, A. *2061 Evaluation Tool*. Available online: http://www.project2061.org/publications/articles/roseman/roseman2.htm, [retrieved on October 31, 2006]

Arapoglou, A., Mavoglou, C., Ikonomakos, I., & Fytros, K. (2006). *Informatics for gymnasium*. Athens: O.E.D.B.

Arcavi, A. (2003). The role of visual representations in the learning of mathematics. *Educational Studies in Mathematics*, *52*, 215–241. doi:10.1023/A:1024312321077.

Bell, A., & Janvier, C. (1981). The interpretation of graphs representing situations. *For the Learning of Mathematics*, *2*(1), 34–42.

Bishop, A. (1989). Review of research on visualization on mathematics education. *Focus on Learning Problems in Mathematics*, *11*(1), 7–16.

Bliss, J., Monk, M., & Ogborn, J. (1983). *Qualitative data analysis for educational research*. London: Croom Helm.

Carvalho, P. S., & Sousa, A. S. (2006). Should we use colours as symbolic representations of hot and cold? *Physics Education*, *41*(3), 263–266. doi:10.1088/0031-9120/41/3/010.

Cheng, M., & Gilbert, J. K. (2007). Towards a better utilization of diagrams in science education research. In: CD-ROM *ESERA 2007*, *Full length papers*, International Conference in Malmö, European Science Education Research Association (ESERA). Malmö, Sweden.

Claffy, K., Monk, T. E., & McRobb, D. (1999). *Internet tomography. Nature: web matters*. Available online: http://nature.com/nature/webmatters/tomog/tomog.html, [retrieved on May 22, 2007].

Cook, M. P. (2006). Visual representations in science education: the influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education*, *90*, 1073–1091. doi:10.1002/sce.20164.

Crisp, V., & Sweiry, E. (2006). Can a picture ruin a thousand words? The effects of visual resources in exam questions. *Educational Research*, *48*(2), 139–154. doi:10.1080/00131880600732249.

Damianakis, A., Tzavaras, A., Mavoglou, C., & Dadouris, K. (2006). *Informatics for gymnasium*. Athens: O.E.D.B.

Dodge, M. (2001). Imagining the Inner Workings of the Internet. *Mappa.Mundi Magazine*. Available online: htpp://mappa.mundi.net/maps_024/imageq.html, [retrieved on October 1, 2007].

Finkelhor, D., Mitchell, J. M., & Wolak, J. (2003). Escaping or connecting? characteristics of youth who form close online relationships. *Journal of Adolescence*, *26*, 105–119. doi:10.1016/S0140-1971(02)00114-8.

Furió-Mαs, C., Luisa Catalayud, M., Guisasoia, J., & Furió-Gomez, C. (2005). How are the concepts and the theories of acid-base reactions presented? chemistry in textbooks and as presented by teachers. *International Journal of Science Education*, *27*(11), 1337–1358.

Gast, J., & Barford, P. (2004). Representing the internet as a succinct forest. *Computer Networks*, *44*(1), 35–44.

Giakoumakis, E., Gyrtis, K., Belesiotis, V. S., Xynos, P., & Stergiopoulou-Kalantzi, N. (2005). *Applications of informatics and computers*. Athens: O.E.D.B.

Good, R. (1993). Editorial: science textbook analysis. *Journal of Research in Science Teaching*, *30*, 619.

Katz, J. E., & Rice, R. E. (2002). *Social consequences of Internet use: Access, involvement, and interaction*. Cambridge, MA: MIT.

King, A. B. (2006). *Mapping the Unmappable: Visual representations of the Internet as Social Constructions*. Center for Social Informatics Working Paper, Indiana University. Available online: http://www.slis.indiana.edu/csi/wp00-05B.html [retrieved on December 1, 2006].

Kollara, M., Kanellopoulos, D., & Spiliotopoulou, V. (2000). Students' mental models and computer networks: The case of electronic mail. In: CD-Rom *Proceedings of the Pan-Hellenic Conference: ICT in Education*. Patras: University of Patras (In Greek).

Koulaidis, V., & Dimopoulos, K. (2005). The co-deployment of visual representations and written language as resources for meaning making in greek primary school science textbooks. *International Journal of Learning*, *12*(10), 243–254.

Kress, G., & Van Leeuwen, T. (1996). *Reading Images: The Grammar of Visual Design*. London: Routledge.

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction*, *13*(2), 157–176.

Makrakis, V. (1988). *Computers in school education—The cases of Sweden and Greece*. Institute of International Education, University of Stockholm.

Mavers, D., Somekh, B., & Restorick, J. (2002). Interpreting the externalised images of pupils' conceptions of ICT: methods for the analysis of concept maps. *Computers & Education*, *38*(1–3), 187–207.

Mayer, R. E., & Anderson, R. B. (1992). The instructive animation: helping students build connections between words and pictures in multimedia learning. *Journal of Educational Psychology*, *82*, 715–727.

Mayring, P. (2000, June). Qualitative Content Analysis [28 paragraphs]. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research [On-line Journal], 1*(2). Available online: http://www.qualitative-research.net/fqs-texte/2-00/2-00mayring-e.htm [retrieved on December 11, 2006].

McCormick, B. H., DeFantim, T. A., & Brown, M. D. (1987). Visualization in scientific computing: definition, domain, and recommendations. *Computer Graphics*, *21*, 3–13.

Marton, F., & Booth, S. (1997). *Learning and awareness*. Mahwah, NJ: Lawrence Erlbaum Associates.

Panagiotakopoulos, C. (1998). Computer and educational software. In A. Kokkos, A. Lionarakis, H. Matralis, & C. Panagiotakopoulos (Eds.), *Open and distance learning—educational material and new technologies* (pp. 187–326). Patras: Hellenic Open University Publications.

Papastergiou, M. (2005). Students' mental models of the internet and their didactical exploitation in informatics education. *Education and Information Technologies*, *10*(4), 341–360.

Pozzer, L. L., & Roth, W. M. (2003). Prevalence, function and structure of photographs in high school biology textbooks. *Journal of Research in Science Teaching*, *40*, 1089–1114.

Pozzer-Ardenghi, L., & Roth, W. M. (2004). Making sense of photographs. *Science Education*, *89*(2), 219–241.

Rogers, L., & Finlayson, H. (2004). Developing successful pedagogy with information and communications technology: how are science teachers meeting the challenge? *Technology, Pedagogy and Education*, *13*(3), 287–306.

Roth, W.-M., Bowen, G. M., & McGinn, M. K. (1999). Differences in graph-related practices between high school biology textbooks and scientific ecology journals. *Journal of Research in Science Teaching*, *36*, 977–1019.

Schnotz, W., Picard, E., & Hron, A. (1993). How do successful and unsuccessful learners use texts and graphics? *Learning and Instruction*, *3*, 181–199.

Spiliotopoulou, V., & Karatrantou, A. (2005). Students' ideas of webpage and teaching implications. *Educational Review*, *39*, 133–151 (In Greek).

Stern, E., & Roseman, J. E. (2004). Can middle-school science textbooks help students learn important ideas? findings from project 2061's curriculum evaluation study: life science. *Journal of Research in Science Teaching*, *41*(6), 538–568.

Sun, P. C., & Cheng, H. K. (2007). The design of instructional multimedia in e-learning: a media richness theory-based approach. *Computers & Education*, *49*(3), 662–676.

Tobin, K. (1990). Research on science laboratory activities: in pursuit of better questions and answers to improve learning. *School Science and Mathematics*, *90*, 403–418.

Tsui, C.-Y., & Treagust, D. F. (2003). Genetics reasoning with multiple external representations. *Research in Science Education*, *33*, 111–135.

Webb, M. E. (2002). Pedagogical reasoning: issues and solutions for the teaching and learning of ICT in secondary schools. *Education and Information Technologies*, *7*(3), 237–255.

Winn, W. D. (1991). Learning from maps and diagrams. *Educational Psychology Review*, *3*, 211–247.

Wu, H. K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching*, *38*(7), 821–842.

Yan, Z. (2006). What influences children's and adolescents' understanding of the complexity of the internet? *Developmental Psychology*, *42*(3), 418–428.

Yegenoglou, F., Faris, F., & Qadan, Q. (2000). A model for representing wide area Internet packet behavior. Paper appeared in Performance, Computing, and Communications Conference, IPCC. *Conference Proceedings of the IEEE International*, 167–173.