

IMAGES OF 'CELL DIVISION' ON THE INTERNET

Lucia Prinou, Krystallia Halkia

ABSTRACT

The use of images in teaching biology is considered to be of great importance for the comprehension of concepts by secondary school students. Important questions for the didactics of biology, which might be of interest to answer, are concerned with the way images, used in biology classrooms, are selected and designed (whether any criteria have been taken into account referring to difficulties or students' aesthetic preferences), and the way students deal with them. An enormous number of sites, including a large number of images, are available to students and teachers for dealing with subjects, which are provided by the secondary school biology curriculum. This paper presents a research, which is focused on the subject of cell division and it investigates the sort of relevant images that are to be found in sites on the WEB. Moreover, it studies the reactions of students, in the last year of Lower secondary school, vis-à-vis the particular example of images.

KEYWORDS

Biology images, cell division, mitosis, Internet sites, secondary school students

INTRODUCTION

The use of images in teaching biology is considered to be of decisive importance for the comprehension of visualized biology concepts and phenomena by secondary school students. This is true for all science education (Pinto, 2002). In life sciences, the study of the related concepts and phenomena requires a multidimensional approach and, in this case, the use of teaching tools becomes important (Nicolou *et al.*, 1997). Daily, in science classrooms, a large number of images, with written text and the spoken word participate in communicating the relevant meanings (Lemke, 1998). Thus, important questions for the didactics of biology which might be of interest to answer, are concerned with the way images used in biology classrooms are selected and designed (whether any criteria have been taken into account referring to conceptual difficulties or students' aesthetic preferences), as well as the way students deal with them. In a relevant research, Kearsy και Turner (1999) found a difference in opinion between students and their teachers concerning the usefulness of different forms of figures in biology textbooks.

The ever-increasing use of Internet in education has created a new reality. An enormous number of sites, including a large number of images, are available to students, teachers and educators for dealing with subjects, which are part of the secondary school biology curriculum.

This research is focused on the subject of cell division and investigates the sort of relevant images found in sites on the WEB. In addition, a preliminary study was carried out on the ways some lower secondary students respond to particular examples of those images.

BIOLOGY IMAGES IN SCHOOL TEXTBOOKS

Images, which first appeared in Greek biology textbooks, were mainly photographs of the cell and its organelles (taken from observation through a light or electron microscope) and some of its abstractive representations. A classic example of an abstractive representation that occurs widely in all textbooks is the phenomenon of cell division studied in this work. These images came mainly from university books, that is to say they were a product of vertical transmission of scientific knowledge into school knowledge, without the necessary transformation, which ought to intervene. Intended for researchers, science experts, etc., they contained too much information for school students to grasp the key concepts. This resulted in a loss of student their interest. These pictures (mainly black and white in the first steps of school biology) do not seem to have had as target a specific didactic function, but merely met the obligation of the authors to illustrate their product text. However, as many researchers have pointed out ‘images are useful tools to help communicating and understanding concepts, processes, interrelations, etc.’ (Kress and van Leeuwen, 1996) and thus, they are not only mere illustrations of a verbal text that are transmitting the essential ideas (Pinto, 2002).

In the course of time, the particularly important role of images as instructive material has been recognized and new images are presented in a large number of drawings and photographs. Pictures drawn are mainly abstractive, that is to say they retain only those elements essential for attracting the students’ attention to key points. It should be noted that in certain cases it was deemed necessary for more ‘elements’ to be added. For example, a representation of a ‘typical cell’ was to be found in the school textbooks, appeared to contain all possible organelles (plastids and centrioles etc.), which actually does not exist. In this particular case, the cell drawn was a didactic “construction” of biology educators. As a result, this functioned as a map-diagram for students at the risk of producing misconceptions.

For the images to function as a means of communication, they require the knowledge of the visually literate viewers. As Kress and van Leeuwen (1996) mention we can talk ‘about a ‘visual language’, a language with a structure and with functions analogous to those of verbal language’, and as Pinto and Ametller (2002) add ‘with its own norms and structures, as does verbal language’. The way of use and the effectiveness of this visual language do not seem to have been adequately investigated. As Pinto (2002) writes ‘The use of visual language is often supposed to be an easier and more efficient way to communicate information, but this idea has not yet been substantiated’. We also share the assessment of Pinto and Ametller (2002) that ‘images cannot be considered trivially understandable and transparent. Misuse of the visual language can affect the communication of the concepts intended to be represented by the image’.

THE IMAGES OF BIOLOGY AND THE INTERNET

Today, biology images are considered to be a dominant factor in education and appear on the Internet as an extension to school textbooks. Many of these biology images on the Internet are not new. They have already been published in books or they are representations influenced by the instructive nature and the aesthetics of the images in books. However, the Internet has been proven to be a very dynamic medium, reinforcing the production and design of new kinds of multimodal science images. Thus, a wider public apart from experts could better know photographs of certain biological phenomena, taken through a microscope, through the Internet. These images can be directly accessible today to a worldwide public and particularly to students and teachers. Thus, all students, even those living in remote places, have the opportunity to access the visual wealth offered by the Internet. The same is true for teachers, who, wishing to overcome the limited visual material traced in textbooks, enrich their courses by alternative and innovative images found on the Internet.

Today, modern technology makes possible broader and even evolving images through a microscope. These images depict in an attractive way, concepts of biology provided for secondary education. At the

same time they affect the development of the way of representing these concepts, by adding new possibilities to their presentation.

Images are considered to be an important element of education, because they constitute an organic element of communication. It is a fact that new technologies have also 'increased the typology of visual communication and the possibilities of creating new images and of manipulating them. Therefore the information society is creating a culture in which images acquire a higher profile as a way of communication' (Pinto 2002). This culture is necessary for the evaluation of the plethora of biology images found on the Internet. As Carney and Levin (2002) point out 'The ease with which instructors can add pictorial elements to Web-based course representations will likely lead to their proliferation in the future'.

DIFFICULTIES IN STUDYING CELL DIVISION IN CLASSROOMS

Several researches indicate the problems faced when students try to comprehend the phenomenon of mitosis. Thus, it seems that the actual understanding of cell division appeared to be limited, confused and inconsistent. Actually, although students seem to have some kind of understanding of the purposes of cell division, they appear to have little understanding of the actual processes of the phenomenon (Lewis *et al.*, 2000). As Bahar (1999) points out 'One of the main problem areas about students' difficulties in learning biology lay in the topics of Mitosis and Meiosis. Because of their similarity, teaching them side by side added to the confusion between them'. In other cases students seem to be able to make a distinction between mitosis and meiosis, but recognize only mitosis as cell division. (Lewis *et al.*, 2000).

Moreover, the research carried out by Lewis *et al.* (2000) reveals that students had an almost total lack of understanding of chromosomes –what they are and what they do. They were confused by the words used to describe the processes of cell division (replicating, dividing, copying, splitting), which could appear contradictory. Their difficulty was often compounded by their inability to differentiate clearly between chromosomes and cells.

In addition to the above traced difficulties in understanding the phenomenon, mitosis is often difficult to demonstrate clearly and in its entirety in a school laboratory (Baggott and Wright, 1996), or by using mere static pictures. Thus, the movement, which characterizes its development, cannot be shown in a school classroom but only through films or animated cartoons that is by using moving pictures. The study of Baggott and Wright (1996) on the use of interactive video in teaching cell division, among first-year undergraduate biology education students, indicated that they find it more advantageous and more motivating in grasping the relevant phenomenon. In this research, most of the students reported that the moving image clarified or enhanced their understanding. It seems that through video, they understood that mitosis is a continuous rather than step-by-step process. Today, the Internet makes this requirement (for being able to present the actual development of mitosis) even easier, making it accessible to all students.

METHODOLOGY OF THE RESEARCH

The research was carried out in two phases: 1) the investigation of the representations of mitosis on the Internet, and 2) the investigation of students' views, on proposed representations of the phenomenon of mitosis (exposure of students to experimental treatment, in order to find out the way they react to characteristic pre-selected images of mitosis on the Internet).

1) Investigation of representations of mitosis on the Internet

The random sample of the research consisted of 112 sites, in which mitosis is represented in various ways. The sources of forming and designing these sites are various, as e.g. academic and research institutions, colleges, educational organizations, private companies with a tradition in producing educational material, individuals seeking to set off and present their work in research and education,

etc. The research was carried out from June to October 2002. The method of analysis and study of the images, which are presented in the above sites, is basically the content analysis.

The presentation of mitosis on the Internet shows the following common characteristics:

In most sites, images are combined with a long or short text. Specifically, either both text and image play an equivalent role in presenting the phenomenon, or the picture plays a prominent role accompanied by short texts. Many of the sites of the first category resemble pages of an electronic book. In almost all the sites, the whole development of the phenomenon is depicted from Interphase to Telophase, with or without movement. The classification of various representations was made on the basis of the intentions of their creators-designers. The largest category concerns representations, which appear to have a specific instructive objective. Thus, they are distinguished in the following categories:

A) Sites of purely *educational character*, which are directed at students, and teachers: The images in these sites according to the classification proposed by Halkia and Theodoridis (2002) are of “mental organization”, that is to say they constitute a proposal for a concise, well-integrated knowledge: ‘Images that usually organize in an abstract way - interpret the accompanying text, like scientific models, sketches, simulations, conceptual maps, flow charts, schematic; symbolic depictions; representations etc. The mental organization refers to the depictions directing the recipient with the assistance of visual elements - symbols (chromatic codes, shadings, arrows and dotted lines, vectors, etc.) or with the help of symbolic representations of the development of a phenomenon in evolution (graphic representations, conceptual maps, flow diagrams, models, etc), so that the recipient can comprehend the concepts of science that are developed or refer to the relevant text. The images of mental organization help students construct solid cognitive structures of the subjects under study’. (Halkia and Theodoridis, 2002).

Sites of this category are the most frequently met (66%). They are subdivided into four categories, according to the sort of images they use:

A₁) Sites, which contain *a sequence of photographs* of the stages of mitosis (Figure 1): They constitute a sequence of photographs shaping a flow chart (16%). In some of these photographs there is an intervention, by using arrows, to underline elements of the phenomenon, which indicates the educational intention of the creators of the specific photographs. This subcategory also includes sites containing photographs accompanied by several teaching activities (informative material that instructs students how to make their own slides of cells so as to observe their nuclei with a microscope during mitosis). These activities intend to involve their readers, pupils or students, in more energetic processes relevant to mitosis e.g. by counting the number of cells found at each stage etc.

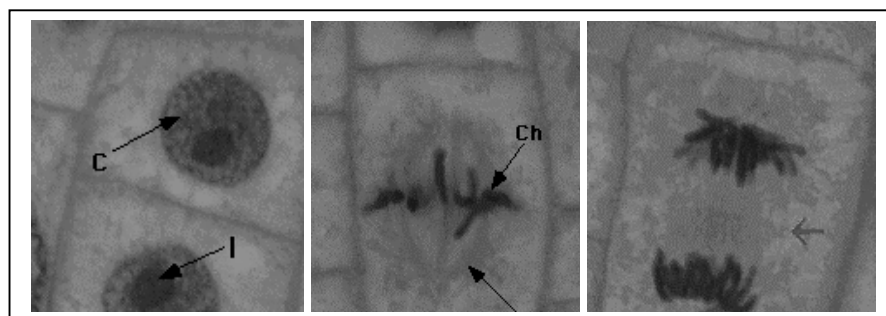


Figure 1

A₂) Sites, which contain *a sequence of sketches-drawings* of the stages of mitosis (Figures 2, 3): They also shape a flow chart of the phenomenon. A main characteristic of all images of that category is that they are representations that describe the process of the phenomenon in a more or less abstract way (27%). Usually, the creators of these images follow the “traditional” way of representing the

phenomenon. But in some of these representations there has been added a sense of “spatial dimension” of cells, in combination with various colors, helping students to better realize the actual phenomenon.

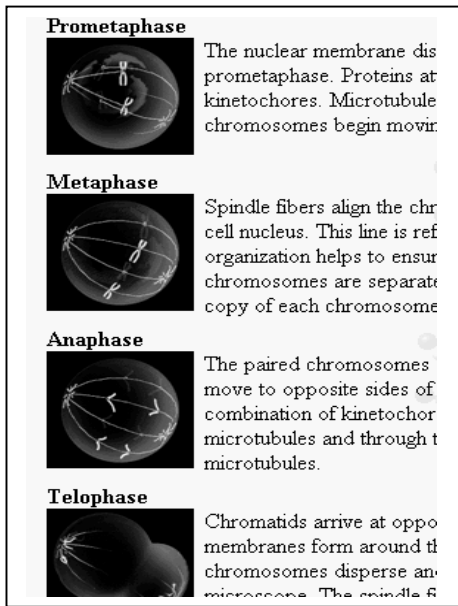


Figure 2

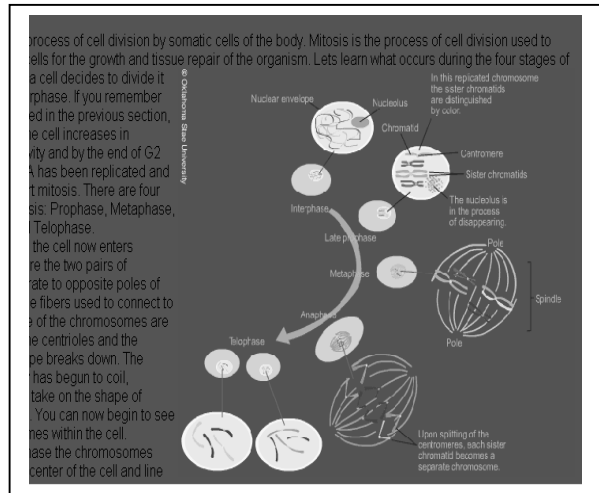


Figure 3

A₃) Sites, which utilize the possibilities of *animation* and depict the development of the phenomenon as a sequence of *moving pictures* (23%): These sites incorporate some interactive features, and they are mainly represented as cartoon like figures. In this category belong:

a) Either sites with very *simple* images, aiming at the comprehension of the basic principles of the phenomenon (Figure 4):

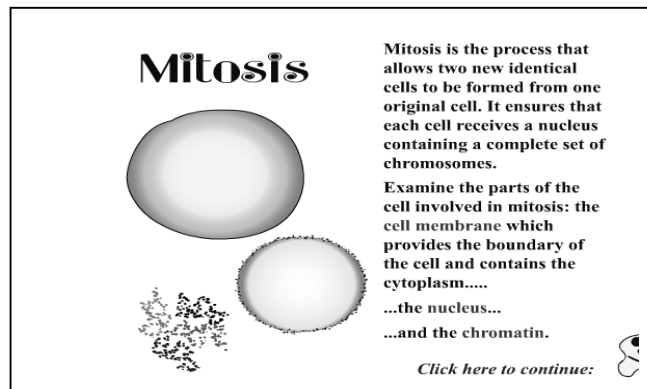
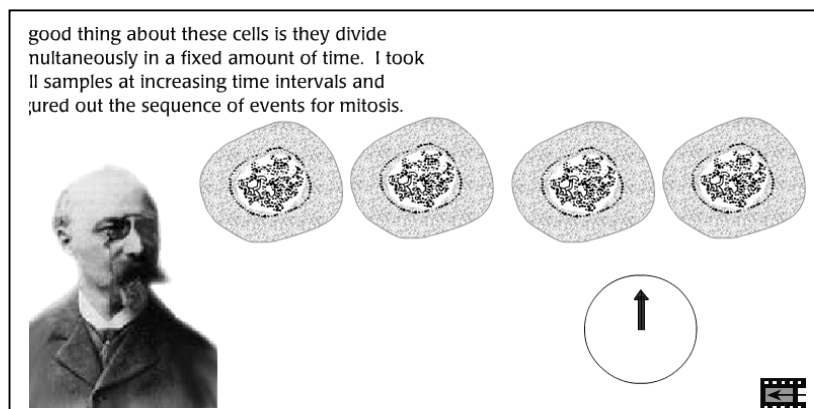
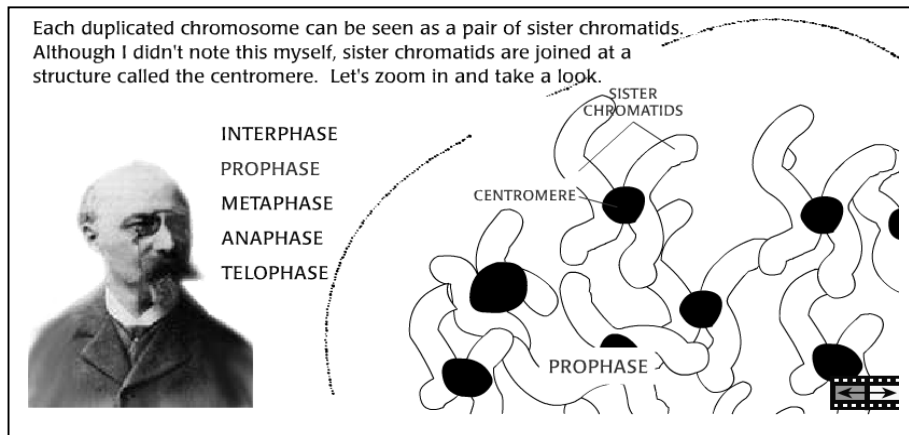


Figure 4

b) Or sites, with images describing the phenomenon in more *detail*, being more consistent with scientific ideas (Figures 5, 6).





Figures 5,6

In this category a small number of sites is also included, presenting the phenomenon in a *multimodal* way, that is to say utilizing various alternative and additional ways of presenting the same phenomenon, thereby providing multiple experiences to the student. These sites combine various images, photographs, diagrams etc with animation, presenting the evolution of the phenomenon in a dynamic way. The images in these sites are not only images of cells at the stages of mitosis, they also present - additionally and separately- specific elements or structures of the phenomenon. These structures can be observed during the development of the phenomenon (e.g. chromosome, kinetochore, spindle apparatus etc). Sometimes, the designers-educators of these relevant representations use various tricks e.g. the chromosomes are symbolized as objects of everyday life - in this case, pairs of forks and knives symbolize the chromosomes.

B) Sites, which combine the phenomenon of mitosis with *technology*: They constitute a “window” to display achievements in technology, referring to techniques of high definition in microscopy and photography (12%). These sites show the modern possibilities of technology and the way in which they are utilized in biology. Sometimes, they are connected to well-known manufacturers of optical and photographic items, which through the impressive photographs of mitosis advertise the technical possibilities of their products (cameras, microscopes, etc). Only indirectly, can these sites be used in education, under the guided instruction of the teacher. In some cases, and mainly in the eyes of non-experts, the result of these photographs is visually impressive. They often appear to exceed the limit of a scientific photograph and to combine science with art.

C) Sites of *research institutions* and agencies that project and publicize the results of their research, in a part of which the mitosis study enters (8%): That is why such relevant papers often contain mitosis pictures. An example of such a type of research is cancer treatment research.

D) Sites, which demonstrate the relation of the phenomenon of mitosis to several other activities (14%), such as: a) Mitosis as a source of inspiration to *artists*: These sites are mainly intended to create an artistic result and do not seem to have any instructive purpose; b) Mitosis as an example of learning how to produce an *animated cartoon*; c) Mitosis as a source of inspiration to *designers of fractals*; d) Mitosis as an argument to corroborate *metaphysical ideas*: In this site, clergymen - members of a religious organization try to support their sermon, referring to metaphysical concepts, by using mitosis animation. Thus, the cell is presented as a member of the church and the organism symbolizes the church.

2) Investigating students' views on proposed representations of the phenomenon of mitosis

As a supplement to the previous phase of the research, an additional preliminary research was carried out, investigating students' responses towards some pre-selected images of mitosis found on the Internet. The process applied is described as follows:

The sample of the research consisted of three groups of lower secondary school students (ninth grade). They had not yet been taught the relevant subject and consequently had not been exposed to the corresponding images of the school textbook. Each group consisted of 4 students. The first group (group 1) consisted of students with high grades in school lessons, the other group (group 2) consisted of students with mediocre grades and the third team (group 3) consisted of students with even lower grades in school lessons, but with a positive attitude towards school and with a variety of out-school interests.

Each group was exposed for one hour to experimental conditions. At the beginning, a very brief introduction to the subject was elaborated to students, so that they could follow the whole process comfortably and participate actively. Pre-selected material was presented to each team (specific representations of mitosis on the Internet).

The criteria for choosing this material were: a) the instructive intentions of the depictions, and b) the variety and the originality of the depictions. Thus, 12 sites were initially selected, belonging in the following categories: a) three (3) sites with photographs of cells observed through a microscope (A_1); b) three (3) sites with abstractive drawings (A_2); c) three (3) sites with moving pictures (A_3); d) one (1) site with multimodal material (A_3); and e) 2 sites with technologically evolved pictures (B). Students were asked to select a representation from each category and then to select from the 5 final representations the one, which, in their opinion, can be used more successfully as instructive material. Students were left free to discuss and argue about the most effective depiction. The whole discussion was recorded and then the relevant discussions were analyzed.

RESULTS

The results of the analysis of the discussion are presented below:

A₁) Sites with photographs

Basic criteria of students' argumentation for the choice of the best photograph are: a) The clarity of the photographs and b) their co-deployment with the text. The groups reject those photographs, which seem to contain too much information for them. They appear to have difficulties in 'reading' them, although they incorporate the appropriate symbols to support their navigation in the study of the phenomenon (e.g. arrows) (Fig.1).

An aspect that appeared to puzzle students was the *layout* of photographs and the relation between text and photographs. Thus, they choose images, which depict the various phases of the phenomenon, and are *linearly sorted*, one below the other, and at the same time being complemented with attendant texts next to each picture. It seems that this layout gives them a sense of flow, which is expressed in their characteristic comments: '*The pictures are one below the other and it is like watching a movie*'. Also, in their discussions it is noticeable that the text that accompanies the pictures is an essential element of the whole 'image'. The three groups were differentiated according to the length of the text. Thus, the students with high and low grades choose short texts, while the students with mediocre grades would prefer longer texts, in order to get more information about each phase of the phenomenon and be able to comprehend it better. This differentiation of groups may be due to the fact that on the one hand the students with high grades manage to "read" the pictures effectively (even with fewer elements in the text), and on the other hand, the students with low grades may find the long text tiring, and perhaps this is the reason why they reject the relevant pictures. Finally, the students with mediocre grades may need more information in the form of text, in order to be able to 'read' the pictures.

A₂) Sites with abstract sketches

All groups chose the same site (Fig.2). Decisive points in their choice were the aesthetics of its images and the fact that they were more informative. Thus, relevant arguments heard were: The specific representation *'has a very beautiful sketch, it is closer to reality, it has a sense of perspective, it is closer to the student's taste'* or it has beautiful bright colors *'which make it attractive to students'*. All groups reject, outright, the other two sites containing more abstract sketches of the phenomenon. There are reasons for this. One was their abstractive nature. With the exception of students with high grades, the abstraction, which inevitably is used to draw a sketch, appears to have been a problem. The rest appear to have had a problem with "reading" the relevant pictures. Another reason is that the images sketched appeared to be naïve to them. Some students characteristically mention, *'the sketches are so simplistic that even we could have drawn them ourselves on the blackboard'*. A significant element in choosing this site is that *'there is a short informative text next to each picture'*. Thus, the text emerges again as an essential element of the image. It is interesting to observe that the students with high grades tried to combine the two sites in order to create a better result. Specifically, group 1 wanted to combine the text of a site, which appeared to be more meaningful to them, with the pictures of the other site that has *'many colors and more details'*. This compositional ability of the students should be particularly emphasized at this point.

A₃) Sites with movement (animation)

In this case too, the students' basic criteria used in selecting the best site were the aesthetics of its images, how informative they are and their combination with the text. Specifically: The 1st and the 3rd group choose the same site because they find *'its picture explanatory, one easily realizes the stages of mitosis, one can watch it in various ways - progressively or continuously, it is projected slowly like a film, it has beautiful colors- is attractive'*. The 2nd group shows a preference for the same site but they do not choose it, because the whole explanatory text *'is found below the picture'*. They choose the site that includes both separate pictures and animation, because *'it is friendly to students, the text is next to the pictures and this helps students comprehend the phenomenon, it has modern style'*.

Site with multimodal material

Students do not show any interest in the pictorial material site - even though they like some of its many pictures. They find the depictions complex as they contain a lot of information.

B) Sites with technologically developed pictures

No group of students appears to prefer the sites with technologically developed pictures, despite the fact that they were impressed by these images. It is interesting that all students found difficult to navigate easily in them and they characterized them: *'impressive, but confusing'*.

Final choice

In their final decision on the most preferable of all sites, students choose as much more advantageous the site with animation (they exclude the rest as static) for: *'its clearer, moving/animated and, for this reason, more interesting picture ('motion doesn't bore'); it is more explanatory; it gives one the possibility to intervene; it is more attractive than the others; it attracts student's attention'*.

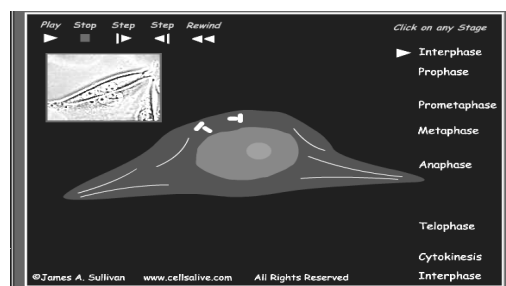


Figure 7

CONCLUSIONS

The Internet has proved to be a powerful educational tool for biology, because not only can it offer a large number of alternative images of the same phenomenon, but it can also provide a numerous of suggestions for the synthesis of relevant educational material. This possibility allows the students to study the phenomenon any time they want and in any way, which would not happen even if their teacher had provided the projection of relevant educational films in the classroom. However, it is useful, for teachers to intervene by choosing and indicating sites on the Internet according to their educational objectives, since, as relative researches show, the effectiveness of pictures depends on educational objectives (Kearsey and Turner, 1999). In addition, as the present work shows, it would be helpful if teachers to take into account their students' preferences as to which images they consider more didactically effective.

The power of messages carried via the ways that Internet develops for the presentation of scientific ideas, necessitates the careful designing of these multimodal «documents». Reasonable questions, which should be answered when such representation is created, are: whether the difficulties, the alternative ideas (representations) or the misconceptions that students have about cells, chromosomes, etc. are taken into account. Additionally, in several times, standardized codes used for the construction of images in biology are taken for granted by their creators, while students seem to have difficulties in perceiving and making sense of the conveyed content, e.g. the cross-sectional cell diagrams, etc. Consequently, it is useful to give students proper instructions how to use such codes. As Kearsey and Turner (1999) mention: “Students need to be taught about grammar of scientific illustration...to support their learning effectively”. In other cases, it is not essential for tricks used in a depiction to allow for a better comprehension of the phenomenon. For example, why it is necessary, for chromatin to be represented in straight lines, dots, or matches and the chromosomes like small bows or forks and knives? Perhaps, in these cases students' imagination may prove to be more inventive and precise (Halkia and Theodoridis, 2001).

As it appears, students see the representation of mitosis as the narration of a story with a beginning, middle and end. They seem to have clear educational criteria in choosing representations of a phenomenon. They are interested in being able to follow the phenomenon of mitosis (that is to say to have all the essential information about it), in being able to comprehend it (that is to say, to be given the opportunity to watch the animation slowly or fast). They also consider that it should have attractive narrative elements in its presentation (colors, motion, relevant text, attractive sketch).

The present research shows that students definitely prefer sketches to photographs. As far as sketches – drawings are concerned, students appear to prefer: a) primarily, the moving picture in presenting the phenomenon; b) the most clear, easily understood drawing – which project the key-points of the phenomenon; c) the drawing that seems to be “closer to reality”. Especially, for static drawings, they seem to demand more realistic elements in the relevant depiction, e.g. a three-dimensional depiction of the cells. But, this depiction of cells occurs in very few sites. d) They also pay attention to the layout of the images presented to them.

An important element that was shown by this research is that students – apart from the picture – attach great importance to the accompanying text, which they consider to be an essential component of every depiction. They prefer these texts to be concise, comprehensive and precise and be placed next to each picture. Thus, students want to combine the information from two sources, confirming Lemke's observations that science concepts are multimedia genres. (Lemke1998). In this way it is proved that each means (text and picture), has its own communication power, but it obeys its own rules. In this case, Internet proves to be a precious source of providing multimodal presentation of the phenomenon of mitosis. Nevertheless, we share Carney's and Levin's (2002) fears, who warned the instructors of the future ‘not to flood learners with adjunct computer graphics, but to deploy them judiciously. An interesting, yet - to - be addressed, empirical question is whether the ‘cyberstudents’ (Wang and

Newlin, 2002) of the new millennium will differ from the book-learned ‘liberstudent’ of the century past, in their ability to process picture and text information comprehensively, and with comprehension’.

Taking into account the limited number of students participated in this preliminary research, an important key issue emerged is that students select photographs which project only the key-points of the phenomenon, that is to say they prefer abstraction in the photographs. Yet as far as abstractive sketches are concerned, students appear to select the most realistic ones. The abstractive sketch is considered to be an important tool in science education for the comprehension of the mechanism of a phenomenon. This is the reason why we should train students gradually educating them “in reading” it, by juxtaposing photograph and sketch (realistic and abstractive depiction of a phenomenon). Very few sites however had such an approach.

A further investigation has been designed concerning the instructive effectiveness of the biology images found on the Internet. It will deal with issues, such as the degree to which sites preferred by the students can contribute in understanding the mitotic cell division and its relation to other relevant very significant concepts of biology.

REFERENCES

Baggot, L. and Wright, B. (1996) .The use of interactive video in teaching about cell division, *Journal of Biological Education*, 30(1), 57-66.

Bahar, M. Johnstone, H., and Hansell, M.H. (1999). Revisiting learning difficulties in biology, *Journal of Biological Education* 33 (2), 84-86.

Carney, R. N., and Levin, J.R. (2002) . Pictorial Illustrations Still Improve Students’ Learning From Text, *Educational Psychology Review*, 14(1), 5-25.

Halkia Kr. and Theodoridis, M., (2001). Latent aspects in science textbooks pictures, *Proceedings of the third International Conference on Science Education Research in the Knowledge Based Society*, II, 850-852.

Halkia, Kr. and Theodoridis, M., (2002). The use of image in Science school textbooks: a system of classification and evaluation images, *Themes in Education*, Ed. Leader Books, 3(1), 79-95.

Kearsey, J. and Turner, S., (1999). How useful are the figures in school biology textbooks? , *Journal of Biological Education*, 33 (2) 87-94.

Kress, G. and van Leeuwen, T., (1996). *Reading images: the grammar of visual design*, Routledge, London.

Lemke, J (1998). *Multiplying Meaning: Visual and Verbal Semiotics in Scientific Text*. 87-113 in *Reading Science, Critical and Functional perspective on discourse of science* edited by J.R. Martin and R. Veal, Routledge London.

Lemke, J (1998). *Teaching All the Languages of Science: Words, Symbols. Images and Actions* Unpublished Paper for Barcelona Conference at <http://academic.brooklyn.cuny.edu/education/jlemke/papers/barcelon.htm>

Lewis, J., Leach, J., Wood-Robinson, C. (2000). Chromosomes: the missing link - young people’s understanding of mitosis, meiosis and fertilization *Journal of Biological Education* 34 (4), 189-199.

Lewis, J., Leach, J., Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance – do students see any relationship *International Journal of Science Education* 22(2), 177-195.

Nikolou, E., Mikropoulos, T. A., Katsikis, A. (1997). Virtual Realities in Biology Teaching, In International Conference Virtual Reality in Education & Training, Loughborough, UK, 59-63.

Pinto, R (2002). Introduction to the Science Teacher Training in an Information Society (STTIS), International Journal of Science Education 24(3), 227-234.

Pinto, R. and Ametller, J. (2002). Students difficulties in reading images Comparing results from four national research groups, International Journal of Science Education, 24 (3), 333-34.

Figure 1 at <http://old.jccc.net/~pdecell/celldivision/oniontip.html>

Figure 2 at http://www.biology.arizona.edu/cell_bio/tutorials/cell_cycle/cells3.html

Figure3 at <http://biotech-adventure.okstate.edu/low/basics/mitosis/mitosis-diagram/>

Figure 4 at <http://stweb.peel.edu.on.ca/sssweb/SNC1D/Edmatters/Biology/Biology.htm>

Figures 5-6 at <http://www.dnaftb.org/dnaftb/7/concept/index.html>

Figure 7 at <http://www.cellsalive.com/>

Lucia Prinou
Department of Education (P.E.)
University of Athens
Navarinou 13A
10680 Athens
Greece
Email: lprinou@yahoo.com

Assistant Professor Krystallia Halkia
Department of Education (P.E.)
University of Athens
Navarinou 13A
10680 Athens
Greece
Email: kxalkia@primedu.uoa.gr