IMAGES OF THE ELECTROMAGNETIC SPECTRUM ON THE INTERNET

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ABSTRACT
This work analyzes a substantial number of electromagnetic (E/M) spectrum images found on the Internet. Ninety-five (95) relevant network sites were studied and sixty-nine (69) different ways of E/M spectrum depiction were collected. These images were studied and analyzed in several 'structural items', thus developing a taxonomy that indicates the problems, the solutions, the 'mistakes', as well as the deadlocks resulting from many different approaches attempting to represent the theoretical model of the E/M spectrum. In addition, several images that served as characteristic examples of our classification were given to three groups of students to observe and study. The students were asked to choose an image from those presented to them, in order to serve as the best representation to be included in a new high-school physics textbook. They discussed and argued their choice and their dialogues were recorded and analyzed.

KEYWORDS
Electromagnetic spectrum, image, students, secondary education, Internet

INTRODUCTION

The electromagnetic spectrum is of special interest in science education, because students do not have direct experience of the subject, and thus cannot easily construct the relative knowledge. The various forms of depiction of the E/M spectrum condense and organize a plethora of information, as many of science images do (Mathewson, 1999). So, it is of great importance to study these depictions on the Internet, because many of these are disseminated in school textbooks or other educational materials and are used by the teachers in the classrooms.

In this work, the Internet serves as a field of research for the study of the various ways developed by research institutions for the visual representation of the electromagnetic (E/M) spectrum. The importance of the proper use Internet in science education, as well as proposed ways for such an efficient use have been many times pointed out (Linn, 2000; Davis and Linn, 2000; Clinch and Richards, 2002). The variety of sources in the Internet allows the detection of alternative ways of image construction, which aim at the organization of information and the creation of the corresponding mental representation in the recipient (Lemke, 1998; Kress and van Leeuwen, 1996).

The present research aims mainly to design a detailed map of the ways the scientific knowledge of electromagnetic spectrum is depicted and the pinpointing of the strong points as well as the weak points of these representations. Complementary to this, a preliminary study was carried out on the ways the high school students respond to different types of those images.

A BRIEF HISTORY OF THE ELECTROMAGNETIC SPECTRUM

The representation of the E/M spectrum has demanded many years of piece-by-piece construction; the result of the efforts of many people.

In the nineteenth century, physicists developed a theoretical and mathematical basis that tied electricity and magnetism together. The electromagnetic theory was a major success of nineteenth-century physics. Not only did it specify the relationship between electricity and magnetism, but it also predicted the existence of electromagnetic waves and showed that light is simply one type of electromagnetic wave.

In 1800 and 1801 Herschel and Ritter, respectively, discovered that there are regions of the spectrum invisible to the human eye. Infrared light was the first 'invisible' form of electromagnetic radiation to be discovered by Herschel, while ultraviolet radiation was discovered a year later by Ritter. Optical radiation was eventually subsumed under a larger category, namely the electromagnetic spectrum, which limited light rays (now including the infrared and the ultraviolet) to a tiny portion of the entire invisible spectrum.

Electricity and magnetism were first associated, during the first decades of this century, mainly through the works of Oersted, Faraday and Ampere. During the next few decades, additional investigations produced evidence that electricity and magnetism were closely related to each other. Finally, in 1865, Maxwell mathematically explained the links between electricity and magnetism and speculated that the two phenomena were so closely bound that they often acted together as electromagnetism. In 1887 Hertz verified Maxwell's theory for electromagnetic waves of slower frequencies (e.g., radio waves), when he produced and detected these in a laboratory.

The different wavelengths and frequencies comprising the various forms of electromagnetic radiation are fundamentally similar in that they all travel at the same speed, the speed of light. The wavelength of light is inversely proportional to frequency. An increase in frequency produces a proportional decrease in the wavelength, with a corresponding increase in the energy of light.

Across the electromagnetic spectrum the energy levels can vary to a significant degree depending upon the energy of source electrons or nuclei. For example, radio waves possess significantly less energy than do microwaves, infrared rays, or visible light, and all of these waves contain far less energy than ultraviolet light, X-rays, and gamma waves. So, the energy of an electromagnetic wave is directly proportional to its frequency and inversely proportional to its wavelength. Thus, as frequency increases (with a corresponding decrease in wavelength), the electromagnetic wave energy increases, and vice versa.

THE ROLE OF THE MULTIMODAL REPRESENTATION OF THE E/M SPECTRUM

Many researchers in science education have pointed out the crucial role of science images in the comprehension of science concepts (Kress and van Leeuwen, 1996; Pinto and Ametller, 2002). At the same time, the problems arising by the 'wrong reading' of science images have been thoroughly studied (Halkia and Theodoridis, 2001). As Stylianidou (2002) mentions: 'It is too often supposed that images are 'transparent' –that they yield their meaning directly and simply. The analytical tools we have found it useful to employ suggest that this is not at all the case –that quite complex and subtle organizations of elements structure the meaning of images'. As the above researcher stresses: 'pupils interpret information through their own conceptions'. Thus it is very important for science education to focus on the possible problems found in the alternative representations of a science concept found on the Internet. Some of the possible difficulties met when the students try to 'read' science images are listed in the above-mentioned article (Stylianidou, 2002).

A characteristic example of that type of representation is the E/M spectrum whose images synopsize and organize a large amount of information in a multimodal way. For that reason, it is interesting to investigate the alternative ways of organizing information, in its many images of E/M spectrum found on the Internet. These usually represent the propositions of well-known research centers on the subject.

The 'concept' of electromagnetic spectrum belongs to the semiotic 'hybrids', according to the terminology introduced by Lemke (Lemke, 1998). To be understood and be communicative, it demands the simultaneous use of textual, mathematical and visual-graphical components. The E/M spectrum utilizes most of the multimedia genres used in science: it combines, interconnects and integrates several visual genres, like numerical values, graphs, drawings, pictures, written text, etc. In that way, there is a multiplication of the meanings made by each semiotic modality (Lemke, 1998).

METHODOLOGY

The research was carried out in two phases:

a) The investigation of the visual representations of the E/M spectrum on the Internet, the construction of a detailed map about the ways the scientific knowledge of E/M spectrum is depicted and the pin-pointing of the strong points as well as the weak points of these representations.
b) The preliminary study on the ways the high school students respond to different types of the selected images of the E/M spectrum.

1st phase of the research

The sources of the research on the Internet
The search in several Internet sites was carried out from June to December 2001. The selection of the images was done through the use of the relative Internet sites –such as research centers (mainly those specializing in astrophysics like NASA, the Hubble Space Telescope etc.), Universities (like Harvard, Berkeley etc.) or educational organizations. It was also done through the Google machine to reliable international academic centers, to private research organizations, to private companies selling apparatus, etc. The relevant sites traced come from all over the world, with a clear domination of those coming from the USA.

The final selection of the collected images was done with the criterion of divergence in presenting the relevant information and of the originality of the way they present their content, so that the final sample does not include similar images. The basic aim was the investigation of the way scientific information is constructed in a visual representation.

The methodology of studying the visual representations of the E/M spectrum
Every single visual representation of the E/M spectrum was analyzed (deconstructed) in its basic structural elements, e.g. in the "languages" or the codes used to organize the information (numerical values, diagrams, symbols, small symbolic icons, text, etc.), so it can be easily transmitted in an attractive way to its receivers. Also, the communication levels used by each single one of these representations with several target groups (the scientific community, the teachers, the students, the lay public, groups of people with special interests etc.) were traced.

RESULTS OF THE FIRST PHASE

Ninety-five (95) relevant Internet sites from all over the world, with 69 different representations of the E/M spectrum, were located.

The framework of the analysis

The analysis of these representations revealed that the E/M spectrum visual information is –in spatial terms– organized in three (3) basic visual zones:
1st Zone: It contains the terms and names of the several regions of the E/M spectrum.
2nd Zone: It provides information about the wavelength (λ) or/and the frequency (ν), or/and the energy (E) of the several regions of the E/M spectrum.

3rd Zone: It gives information about the technological applications of the several regions of the E/M spectrum, as well as about their influences on human health.

Each one of the above zones utilizes up to five (5) ways of visual representation, and usually exploits different "languages" and codes of communication, like the use of numerical values, graphs, diagrams, symbols, small symbolic icons and text.

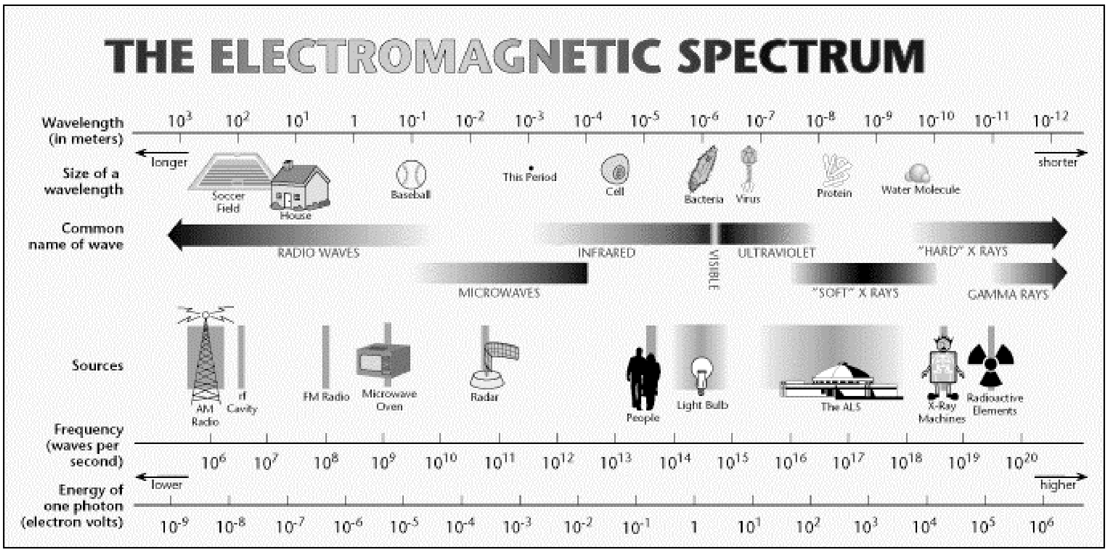

Figure 1. A representative image of the electromagnetic spectrum

The ways of visual representation of the different E/M spectrum zones on the Internet

1st Zone: The zone of reference (The regions of the E/M spectrum):

a. Zone divided into specific regions (γ rays, X-rays, ultraviolet, visible, infrared, microwaves, radio waves). (98.6% of the total visual representations)
b. The use of symbols (arrows, color, etc.) for the representation of the area and the overlapping of the several regions of the E/M spectrum (73.9%).
c. Analysis of the visible region in the colors of the rainbow (Point of reference for the several regions of the E/M spectrum). Elements which appear in such an analysis are:
    i. The colors which compose the visible spectrum (73.9%).
    ii. The sun as the source of the emission of the visible light (7.2%).
    iii. Any other source of emission of the visible light (2.9%)
d. Text with relevant information (49.3%).

2nd Zone:

The zone of science (Information about the wavelength λ (91.3%) and/or frequency f (49.3%) and/or energy E (13%))

a. Quoting of numerical values (85.5% of all the visual representations).
b. Use of symbols (arrows showing the direction of the increase of λ (40.6%).
c. Graphs of λ.
    i. A continuous line to depict the continuously changing λ (21.7%).

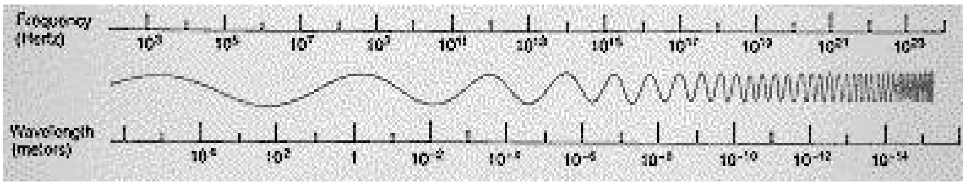

Figure 2. The use of a continuous line to depict the change in wavelength

ii. A break-off line to depict the continuously changing λ, in fragmented regions of the E/M spectrum (1.1%).

iii. Separate lines of changing λ, related to each region of the E/M spectrum (4.3%).

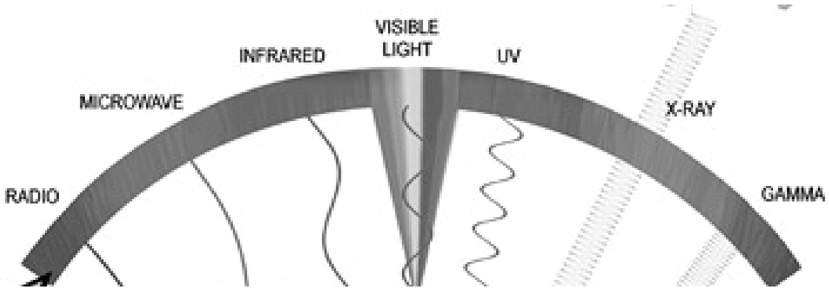

Figure 3. The use of separate lines for the changing wavelength

iv. Separate lines of λ, depicted only at the two edges of the E/M spectrum (1.1%).

d. Small symbolic icons showing objects relative to the size of λ for every single region of the E/M spectrum (8.7%).

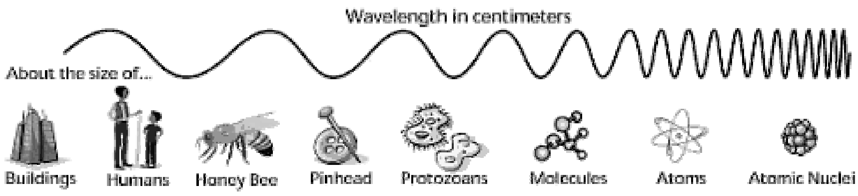

Figure 4. Using small icons of objects relative to the size of each wavelength

e. Text with information about λ mainly (30.4%).

3rd Zone: The zone of everyday life (Technological applications in everyday life – Influences on human life)

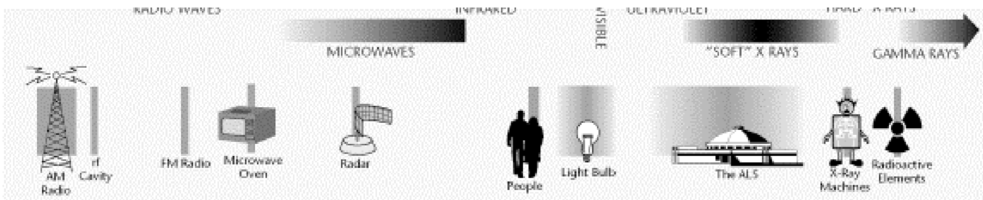

Figure 5. The use of icons showing sources of E/M radiation

a. For every single region of the E/M spectrum, small symbolic icons appear showing technological applications in everyday life or influences on human health (23.2%).

b. Relevant text presenting information about these applications (21.7%).
c. Simple words referring to characteristic applications in each region of the E/M spectrum (4.3%).

PROBLEMS TRACED IN THE VISUAL REPRESENTATIONS OF THE E/M SPECTRUM

A further exploration of the selected images revealed the visual solutions, as well as the visual dead-ends which are involved in every kind of effort to render visually the theoretical model of the E/M spectrum. It should be stressed that although most of these images come from sites of reliable sources (international research centers and universities), they often embody several deficiencies and errors.

It is important to point out the most common errors found in E/M spectrum images, because many teachers tend to pick up and use these images in their everyday school practice, without further investigation, since they are usually derived from a high status source. These errors are:

1. Graphs presenting *a continuous increase of the wavelength (λ)*, along the zone of the E/M spectrum, without any indication of the symbolic use of such a 'graph', or of any other reference (75% of the total sum of the attempted visual representations of λ). In that way, the designers of this type of 'graph' were trying to point out, in a very concise way, that each particular point of the E/M spectrum zone corresponds to a distinctive wavelength, with constant frequency. But, on the other hand, since such a 'graph' reminds the viewer the actual graph of the wavelength, it could confuse students and mislead them into the alternative conception that there is only one wavelength for the whole zone, with continuously changing frequency. Thus a highly original visual solution can often create confusion in students' minds. The most remarkable thing here is that most of the images found, include such a representation.

2. Very often, the *small symbolic icons used in the same image are mixed*, and do not refer to similar applications of the E/M spectrum (e.g. transmitters, receivers or influences on human health), but in some region of the E/M spectrum they represent transmitters, in another receivers and in some other dangers for human life (50%). Additionally, in many cases, these icons are size - misleading because they have been designed with different, arbitrary scales. It seems that the designers of the relevant image apparently intend merely to make it attractive. But these images often luck consistency.

3. In many images, *the sun appears to be the only source of light radiation in the visible region of the E/M spectrum*. Moreover, the sun appears to emit only in the visible region and not in other regions of the E/M spectrum (71% of the images showing sources of radiation). This kind of representation may create a misleading perception in students' minds. They might consider that the sun emits light frequencies only in the visible spectrum.

4. The *semiotic use of colors for the wavelength of the visible region often extends to cover the wavelengths of regions beyond the visible one* of the E/M spectrum (18.8%). Such a mixed use of color codes might confuse students, because it could convey to them the idea that radiations of visible light might somehow also be emitted by other regions (beyond the visible) of the E/M spectrum.

The several regions of the E/M spectrum are often separated by sharp distinctive limits (lines) between them and there are not overlapping areas between the neighboring regions (29%).

2nd phase of the research

Additional data were gathered by investigating students' ideas about several of the collected images representing the E/M spectrum. The selection of the images presented to students was guided by the problems in the depiction of the E/M spectrum, traced in the first phase of the research:

a) images which represent different ways of depicting the change of wavelength. (image with a continuous line to depict the continuously changing λ, image with separate lines of changing λ related to each region of the E/M spectrum and image with separate lines of λ depicted only at the two edges of the spectrum;

b) images which deploy numerical values for the wavelength and/or frequency;
c) images which include small symbolic icons showing objects relative to the size of λ for every single region of the E/M spectrum;
d) images which include sources of electromagnetic radiations in different regions of the E/M spectrum.

Research questions:
Which image of the E/M spectrum will they choose and why?
Which do they believe is the best representation for the depiction of the change in wavelength from region to region of the E/M spectrum and why?

The participants were all 12th grade high school students, selected from an Athens' high school. They all attend a course with science as its major subject, thus having the same E/M spectrum background knowledge. Therefore, what they already knew about the electromagnetic spectrum wouldn't influence their observations.

These 12th grade students were divided into three groups according to their physics marks in the national exams. The students of the first group (group 1) were high-performing students in physics. The second group (group 2) consisted of students with medium performance in physics, while the third group (group 3) consisted of students with even lower —though not particularly low— performance in physics, but with a positive attitude towards science lessons in general, since they all wanted to be science majors. Each group consisted of four students (two males and two females) who were randomly selected and were given the same 8 different images of the E/M spectrum to observe and study.

They were asked to choose an image from those presented to them, in order to serve as the best representation to be included in a new high-school physics textbook, in the section covering the topic of the electromagnetic spectrum. The students, working as a group, were left free to discuss and argue their choice of the best image of the E/M spectrum. The dialogues were recorded and these audio recordings were later analyzed. Their discussions were recorded in an attempt to identify the students' views and attitudes towards the presented images, their criteria in selecting them, as well as their ways of 'reading' them.

RESULTS OF SECOND PHASE

Lots of useful categories of analysis were developed.

1. *The numerical values characterizing the relevant wavelengths and frequencies:* Groups 1 and 2 considered absolutely necessary the appearance of the numerical values characterizing λ and f, in different regions of the E/M spectrum, while group 3 made no comment on that. Additionally, members of group 1 mentioned that the use of numbers for the wavelength is very helpful. ("*It is very good that it gives you the scale (in nm) because no one is going to use a ruler in order to measure it").*
2. *The use of symbolic icons indicating the sources of electromagnetic radiation:* Group 1, consisting of high-performing students, selected the image which includes icons referring to sources of radiation. In contrast, the other two groups considered that the image which includes these icons is conceptually heavily loaded and therefore they have rejected the corresponding image.
3. *The plethora of information:* Group 1 seems to be able to comprehend images with a lot of information in them and therefore selects the image which is conceptually heavily loaded, and moreover, they suggest combining two images to include even more information. The other two groups rejected images with a lot of information in them and they prefer images containing the 'essential' information ('*which is clear, simple and presents fewer concepts than the previous ones'*).
4. *The use of a continuous line to depict the continuously changing wavelength:*
All groups regard as a very powerful depicting element the use of a continuous line to present the change in wavelength across the regions of the electromagnetic spectrum. They rejected a picture,

which although it embodied many good qualities (according to them), did not depict this change in wavelength with a continuous line. In supporting the use of such an image, students had as an argument that the continuous line "*is a very nice way to depict the change in wavelength, since one can learn it more easily"* and that this kind of depiction *'is very helpful, because it allows you to actually 'see' the change of the wavelength across the E/M spectrum zone'.*

In the question about which picture they think has the better depiction for the change in wavelength, all groups rejected the picture that uses a separate line of changing wavelength, related to each region of the E/M spectrum. They all said that they couldn't understand that these 'lines' represented the wavelength. *('It looks like a straight lines (in radio-waves with large λ), it is confusing, some students might think that wavelength can be depicted by a straight line').*

Group differences

The above results revealed some differences between the three (3) groups of students.

1. The findings indicate that the high-performing students group 1 in contrast to the students of group 2 and 3, prefer an image that has as much information as possible, provided that this information is well presented and organized. These findings seem meaningful if we assume that the ability to 'read' a self-contained image with lots of information is enhanced for students with better performance. Also, it is revealed that the students of group 2 and 3 would prefer the additional information about the E/M spectrum to be given in a text accompanying the image selected. Students of group 2 and 3 regard the picture selected by group 1 as *'complex, showing too many things, too much information, would appeal to people of higher education level'.*
2. Only the students of group 1 noticed and mentioned that there was no reference to the medium, and that the numbers shown for the wavelength in every picture corresponded to the wavelength's value in a vacuum. It is known that upon entering a new medium, the speed and wavelength of light is changed, although the frequency remains unaltered. This could be the reason why students of group 1 also stated that they could not choose as the most representative an image that does not contain any information about the *frequency* of electromagnetic radiation.

CONCLUSIONS

The analysis of the visual representations of the E/M spectrum leads to the following conclusions:

All E/M spectrum images found on reliable Internet sites, consist of up to five (5) basic visual structural units. The creators-designers of the E/M spectrum images seem to consider that these structural units embody the necessary prerequisites for the conceptual understanding of the kinds of information summarized in the relevant images. They utilize several ways to represent the relevant information in these basic structural units and to communicate to the lay-public. These are extended from the abstracted graphs to the small symbolic icons with references to everyday life. In that sense, the researchers communicate with several groups of people (teachers, students, lay-public) by means of data which use not only a strict and abstract mental code, but a more loose and emotional code, with a lot of narrative and popularizing elements.

The creation of an image, which manages to visually represent complex and concise scientific information with a friendly and understandable code, is not an easy task. That is why, the attempts to visualize the parameters of the E/M spectrum, like the wavelength, in many cases has led to visual dead-ends. Thus, a single line with continuously varied time period is intended to represent the continuous changing of the wavelength from region to region of the E/M spectrum. This kind of visual representation can easily lead its viewers to misconceptions, especially when it is not accompanied by a relative indication explaining the symbolic nature of that 'graph'. This problem seems to have been realized by a few researchers, on a limited number of Internet sites, who have tried to overcome it in the following ways: a) by interrupting the continuous line of the representation of the wavelength in the limits of the neighboring regions (1,1%), b) by presenting different representations of the wavelength in each E/M spectrum region (4,3%) and c) by submitting only two separate representations at the two edges of the E/M spectrum, thus making obvious the difference of the wavelength (1,1%).

The results and consequently the conclusions based on phase 2, although they are confined by the small number of students participating in it (preliminary study), might indicate directions for further research. In that respect, an interesting point to be noticed is that the findings of the 2nd phase of the research done with students, reveal that the depiction of the changing of the wavelength with a continuous line, strongly appealed to the students, who rejected all the other efforts to depict the change of the wavelength more precisely. Thus, teachers should be very careful when they present some images to their students. The impressive images are not necessarily didactically effective.

Another important finding of this research is that it seems that students with different abilities 'read' the science images in a different way. Thus, the group consisting of school achievers prefers images with a lot of information in them (independent of any text), while the other groups prefer simpler images with less information in them, supported by an accompanying text. This finding suggests that we might provide images with different levels of 'difficulty' to groups of students with different abilities. Another crucial point is the role of text in 'reading' an image, especially when we are addressing average students.

According to the above, it is clear that the visual 'reading' of a representation of the E/M spectrum demands visually literate users. This is of special interest in science education, because lately many science teachers, writers of science textbooks, designers of science software, and students, often visit reliable sources (sites) on the Internet. Their main aim is to utilize the suggested visual representations of physical phenomena in their everyday school practice.

Moreover, it is important to point out that the attempts of popularizing and of transforming scientific knowledge into school knowledge may lead to some form of visual representation with a friendly and attractive communication code, which very often includes 'mistakes', responsible for the creation of possible alternative conceptions in students. In most cases of visual representations of the E/M spectrum, it has been noticed that, *'the fewer the visual elements in a picture the fewer 'mistakes' and deficiencies have traced'.* Thus, the popularization of an image, which is meant to convey scientific information, is a difficult task. It should be designed and accomplished by visually literate scientists and should be critically utilized by teachers and students.

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The images presented here were taken from:
Figure 1 and 5: www.phys.virginia.edu/classes/usem/sciimg/Introduction/Introduction.htm
Figure 2: http://blueox.uoregon.edu/~courses/BrauImages/Chap03/FG03_009.jpg
Figure 3: www.spacetoday.org/DeepSpace/Telescopes/GreatObservatories/Chandra/ChandraSpectrum.html
Figure 4: http://imagers.gsfc.nasa.gov/ems/waves3.html

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