DIFFICULTIES IN REPRESENTING MICROSCOPIC PHENOMENA ON THE INTERNET: THE CASE OF BROWNIAN MOTION

Kyriaki Dimitriadi & Krystallia Halkia

ABSTRACT

Brownian Motion is the motion during which the particles suspended in a fluid move in a random way in all directions. Randomness is a key concept in understanding the phenomenon. Also, because it refers to molecular motion, microscopic approach is required. In addition this phenomenon combines both mathematics and the laws of physics and it has applications to everyday phenomena.

On the Internet 30 applets were found, from university and college sites mostly, but also from high schools, companies which create educational software for the internet and individuals. These applets are available to teachers and students as well to the public, so they constitute a very powerful informal source of learning.

With the use of computer science, not only the visualisation of the phenomena can be achieved, but also their reproduction, according to the laws of Physics which govern them. Apart from the advantages of the Internet in science education, it is important to point out the problems which can arise during its use, since it is difficult to visualise microscopic phenomena according to the valid scientific models.

KEY WORDS

Brownian motion, micro cosmos, representation, randomness, Internet, simulation, depiction

INTRODUCTION

In science education many are the times when we have to study phenomena which we cannot observe directly. These phenomena are those which:

a) have to do with micro cosmos (elementary particles, atoms, molecules) or mega cosmos (solar system, galaxy, cluster of galaxies, etc.)
b) their speed of development makes their observation difficult (some phenomena develop in a split second, whereas some other in days, months, years, etc.) and
c) for their study experiments are necessary which are dangerous (Clinch et al 2002).

So, in many instances their representation and reproduction is used in the educational procedure. This offers unique opportunities for their intellectual assimilation. At the same time though, there are notable dangers. These dangers are prominent mostly when the role of the represented structures requires explanation. This refers to entities of the real world, to symbolic entities but also to entities represented in a multiple way by a combination of two or more pictures. (Stylianidou et al 2002) This project studies the representations of the Brownian motion, as these have been found in different sites on the Internet. Through the case of Brownian motion which is a microscopic phenomenon, we will study:

- ways that microcosmos is represented

- educational and scientific models which are used in the representations that refer to microcosmos, and
- the difficulties which arise during the representation of the phenomena on which emphasis will be laid.

Brownian motion is a unique phenomenon for these aims. This is because it is a microscopic phenomenon, it is characterised by randomness, it combines both mathematics and the laws of physics and it has applications to everyday phenomena.

VISUALISATION OF PHYSICS PHENOMENA

Science education deals with a serious problem when it attempts the study and the approach of phenomena that the students cannot observe directly in their daily life. In this instance, science education pursues the representation of the phenomena, using models according to valid scientific theories. In this way, students can create the desired mental images. This can be achieved in several ways, but computer science which is used more and more in education is an especially dynamic and important instrument for this aim.

In science education nowadays it is recommended the phenomena which cannot be observed directly, should be reproduced and represented. With the use of computer science, not only the visualisation of the phenomena can be achieved, but also their reproduction, according to the laws of Physics which govern them, using random numbers. In this way, the randomness of Nature's procedures is taken into account. This randomness is apparent particularly in microcosmos (Monte Carlo methods) (Halkia et al 1997, Hadzidaki et al 2000)

At the same time Internet provides important potentials and opportunities to the educational procedure if they are utilized properly. The access to and the exchange of information have been simplified, whereas each user can try to get information on the Internet for the subject he/she wants. Individualised learning becomes possible because each user can proceed at his/her own pace independently of the rest of the class. The teacher has the role of co-coordinator. Furthermore, students and teachers have the capability to be informed about recent scientific discoveries.

In science education specifically, through Internet, we can access sites which provide many and alternative ways to approach natural phenomena, mostly through their visualisation and reproduction. In this way, the subject can become more interesting and there are facilities for the understanding of subjects which, under different circumstances, wouldn't become comprehensible. At the same time, an experiment which wouldn't be easy to perform can be presented through representations and simulations. This happens to experiments that demand too much or too little time or to experiments that are dangerous. Sometimes, also, there is no appropriate experimental equipment. This presentation can succeed in an interactive way so that the student has an active role. In conclusion, we have to point out the chances that Internet provides to the students and the way they can gather data and information when they carry out a piece of research (Clinch et al 2002)

Without doubt, apart from the advantages of the Internet in science education, it is important to point out the problems which can arise during its use. These result from the fact that the information which is imported, most of the time, is not checked by someone who is responsible. Furthermore, undirected and unfocused 'surfing' on the Internet does not yield much lasting and meaningful learning. Students may spend too much time in recreational web surfing without a clear focus (Clinch et al 2002). For this reason it is essential to evaluate the programs and check the sources. At the same time it is important to direct the students. Moreover, just like every other educational mean, it has to be used in the right way and for the right reason.

DANGERS FROM THE VISUALISATION OF MICROSCOPIC PHENOMENA

As has already been mentioned, visualisation is extremely important for the phenomena of microcosmos, because it is not possible to observe them otherwise. However, the laws of quantum mechanics which govern these phenomena, make the attempt particularly difficult, because their representation according to the valid models is not possible.

This is due to the fact that the laws of quantum mechanics by nature, do not allow the exact specification of the particles' position (principle of indeterminism or Heisenberg uncertainty principle) (Young 1994). So, neither is the representation of the shape of the particles, which consist of other particles, possible. The atom, for example, cannot be depicted with the nucleus at the centre and the electrons moving in orbits around it, etc. For this reason in many instances the representation of microscopic phenomena resorts to:

a) The use of the scientifically and historically surpassed models, like the model of the 'rigid spheres'. This model could operate in a symbolic way for the needs of education, but in the specific visualisations and representations this convention is not obvious. This leads the students to the conclusion that this model is identical to reality.
b) The attempt to make alternative models, representing the particles not as rigid spheres, but with a gently deformed surface. Still there is no explanation that this representation is symbolic, so they do not agree with the contemporary scientific models.
c) The complete avoidance of the representation of microscopic entities. They present other characteristics of the phenomena (Graphs, the track of the particles, etc.)

Another danger is the formation of misconceptions by the students, since the designers of the software, usually, try to attract the users and present interesting material. So they resort to the use of colors and characteristics, that have nothing to do with the entities of microcosmos. They attribute, for instance, human characteristics, or they paint the particles, without mentioning that they operate symbolically and explaining this symbolism.

Misconceptions can also be created by the fact that the users many times focus on wrong points. They lose the main point of the phenomenon, especially when they do not have the necessary knowledge and there is no accompanying annotation. Also, as it has been mentioned above, the pursuit of information on the internet, can prove to be time-consuming, students can waste too much time and they can lose their initial goal. (Clinch et al 2002)

BROWNIAN MOTION

Brownian Motion is the phenomenon which we will study, due to its special characteristics. Extremely interesting is the fact that it can be approached in an interdisciplinary way, since it is governed by mathematic formalism, it is a phenomenon of microcosmos and randomness is a key concept in understanding it. At the same time, there is a historic side, because it had different explanations in different times. Furthermore, it has interesting extensions in daily life.

In Greece the phenomenon is taught in high school but its special characteristics and its extensions do not become perceptible.

Below there is an analytic mention of the phenomenon, its explanation and its history, because it is essential in understanding and pinpointing its special characteristics.

Observing the particles moving in a fluid through a microscope, we can find out that they constantly and randomly move in all directions. The British botanist Robert Brown discovered this motion in 1827 and this is the reason the phenomenon is called Brownian Motion. Specifically, when R. Brown looked through a microscope at small grains of pollen in water he saw some pollen which behaved in a strange fashion. They jiggled around following a zigzag path. Moreover, when the temperature was increased, the movement was more rapid.

R. Brown could not explain his observations. Initially he thought that the grains of pollen moved, because they were alive. Later he found out that particles of dust and soot which are not alive moved in the same way. The phenomenon was not explained until 1905. Then a theory was developed by Einstein, which explained the phenomenon: the movement is due to the invisible fluid molecules hitting the particles continuously from all sides and moving them slightly in a random fashion. The fluid molecules are constantly moving in a random way. This experiment and Einstein's discernment opened the way for the revelation of the molecular flow's secrets. It was also a proof of the atomic structure of the matter. (Serway 1990)

More analytically:

The particles suspended in a fluid move in a random way in all directions, following a zigzag path. This motion is called Brownian motion. This motion depends on the properties of the fluid, but it is not dependent on the particles' material. The movement is more rapid for smaller particles. Furthermore, the higher the temperature, the faster they move. The explanation is that the phenomenon is a result of thermal molecular motion of the particles. A suspended particle is constantly and randomly bombarded from all sides by the fluid's molecules. If the particle is very small, the hits it takes from one side will be stronger than the bumps from the other side, causing it to jump. The next moment the particle will jump in a different direction, and so on. These small random jumps are what make up Brownian motion. (Kostopoulos 2002)

Brownian motion is not molecular movement. It just proves that there are microscopic entities and it is expressed as chaotic motion in space. (Trikalinos 1996)

In Greece Brownian motion is taught in the high school (eighth grade). There is also a mention of molecular motion as applied to states of matter in the eleventh grade for those who have chosen science as their major subject. From personal experience it is obvious that students find it difficult to understand the phenomenon, since its microscopic approach is essential. For this reason, we believe that the use of the appropriate applets could make it easy for the students to grasp the phenomenon. They can also observe the way the phenomenon develops.

This phenomenon combines knowledge both of Mathematics and Physics. It is also characterised by randomness, so it has extensions in various areas of modern research and society in general. So Brownian motion can be described by fractal geometry because of the randomness that characterises it. In this case, it formulates the "fractional Brownian Motion model", which has several applications in areas that are characterised by randomness. (Medical imaging, robotics, estimation of extreme floods and droughts, market analysis, manufacturing, decision making, etc) (Lee et al 1995)

VISUALISATION OF BROWNIAN MOTION

At this point we will mention the special characteristics of Brownian motion's visualisation. We consider it essential because of the special characteristics of the phenomenon. A visualisation like this could help the students effectively in creating the appropriate mental images and to grasping the phenomenon.

It is remarkable that we have the opportunity to observe the results of the microscopic procedures which are not visible. The randomness of the phenomenon can also be concluded. These characteristics make the verbal description of the phenomenon extremely difficult to understand, whereas carrying out "hands-on" experiments cannot reveal its nature. So we turn to the visualisation or/and the reproduction of the phenomenon using hi-tech aids. Computers also make possible the interaction with the student / user, who can find out if and how variations of quantities, like temperature, mass, number of particles, etc., can affect the phenomenon.

The role of the Internet in the approach of the phenomenon is especially important, because contrary to the school books, which present the phenomenon in a stationary way, Internet allows the dynamic approach to the phenomenon. It enables the motion and the observation of the movements' randomness. At the same time it provides extensive material for approaching the phenomenon through alternative ways. In this way its study in school classes becomes easier.

However, due to the special characteristics of the phenomenon, the visualisation of Brownian Motion has a lot of difficulties. If these difficulties are not faced properly, a rash and not well thought out visualisation of the phenomenon can cause misconceptions to the students. Such a difficulty has to do with the image of the microscopic particles, which are difficult to represent in a different way from that of the rigid spheres. This makes the students believe that the particles of microcosmos have a hard "shell" covering them. Furthermore, the role of the randomness could be realised with the use of the Monte-Carlo techniques, which make possible the reproduction of the phenomenon. In many cases, though, creation of formations or repetition of the movements is observed, since they follow the same loop (steps in the computer programming that are repeated). Even though this happens due to software limitations, it can be the cause of wrong impressions and misconceptions to the students.
There is also a difficulty in the use of the right scale and in the transfer to a different dimension. So, the transfer of a grain of pollen, which is suspended in a fluid, in microscopic level is difficult to achieve with the maintenance of the right scale. This means that it is difficult to present simultaneously the grain of the pollen and the molecules of the fluid around it since they each refer to different worlds. Furthermore, the limitations imposed by the software do not allow the representation of the actual number of the microcosmos' particles, which move in a specific area. So they usually represent vary much smaller number of particles.
As a whole, the visualisation of the Brownian motion offers important prospects for the comprehension of its nature, its various dimensions and its other aspects. Of course, this does not mean that we can use every representation we find on the Internet. On the contrary, knowing the educational goals and realising the problems of each representation, we can evaluate the material and place it in the educational procedure in the best way.

METHODOLOGY OF RESEARCH

On the Internet using the search machine Google and inserting the phrase "Brownian motion applets", resulted in 735 hits, in which there were 30 different representations of Brownian motion. Even though in many cases there were common characteristics, on the whole there was an unexpected range of representations.
For the grouping of the applets the following criteria were used:

1. *The aspect of the phenomenon which has been chosen to depict*: Whether emphasis is laid on the qualitative approach of the phenomenon or on the presentation of its special characteristics. So in some applets we see a representation of the entities of the microcosmos, whereas in some others a more abstract representation has been chosen (tracks of the particles, graphs).
2. *The possibility of interaction with the user*: Whether the user can interact with the applet and to what extent this is possible.
3. *The existence of accompanying text*: Whether the representation of the phenomenon is accompanied by relative text, which is regarded essential for the comprehension of the representation. Furthermore, it is important to specify the aim and the context of this text. (For example, if it refers to the use of the applet, to the explanation of the phenomenon, to educational points using relative questions, to the history of the subject, etc.)
4. *The ways the phenomenon is represented*: Whether in the representations of the phenomenon one or more ways exist. So, in some applets there is only one way of representation, whereas in some others the transfer to other levels has been chosen (multimodal approach). The main goal, of course, is the explanation of the phenomenon.
5. *The extensions Brownian motion has in others levels*: If there are other aspects of the phenomenon, beyond Physics. In some cases there are interesting extensions of the Brownian Motion phenomenon. It is combined with various unexpected topics of daily life

or scientific research. This happens due to the special characteristics of the phenomenon, like the randomness of the motion.

RESULTS: WAYS OF PRESENTATION AND POTENTIAL DANGERS

1. There are two main directions in the ways chosen to represent the Brownian Motion phenomenon: A) An abstract representation, limited to the depiction of a particle's track, without the depiction of the actual particle, or B) the more specific representation of the particles themselves, which may lead to students' misconceptions. Specifically:

a) *Abstract representation of the track of the particle*: I) A number of applets (37%) present the track of the particles, using graphs of the position in relation to time, or bars grouping particles displacement. II) In some others, the particle's motion on the plane and the track that is traced (13%) is presented and III) In one applet (3%) we can see the track of several particles in relation to their centre of gravity. In these cases, the randomness of the phenomenon is stressed and the fact that if the phenomenon was to be repeated, particles would not follow the same route and would not have the same track. The representation is abstract and mathematic formalism is mostly used. In this way the creation of misconceptions is avoided, but the phenomenon will probably not be comprehensible to high school students. This is due to the lack of explanation of the phenomenon's mechanism. Remarkable is the fact that the ensemble of these applets has been created by universities. Only one (3%) has been created in an individual's laboratory. This indicates that they are not actually intended for pupils, but for students who are able to understand and grasp this kind of representation.

b) *The "realistic" representation of the particles*: In other applets (27%) emphasis is laid on the qualitative approach of Brownian Motion. Particles and the mechanism according to which they move are represented. It is a fact that this kind of representation seems to be more comprehensible and attractive, especially of high school pupils. At the same time, though, there is the danger of creating misconceptions. They can impose an image for the entities of microcosmos and this is why their symbolic representation should be extremely cautious. I) In most applets (50% or 14% of the total number) the rigid spheres model is used, creating the wrong impression of particles having a hard surface. II) In a lot of cases colors have been used (50% or 14% of the total number). This could contribute to a better representation of the phenomenon. In most cases though, there is no mention of the chromatic scale used in the representation. This leads to a danger of the student believing that the particles have color. III) Another common problem found in the applets is the fact that there is either no scale at all or it is used incorrectly. Thus the grains of pollen are represented a little larger than the molecules of the fluid. In two (7%) cases after the observation of the particle's motion, molecules of the fluid become visible. This happens with or without a small enlargement of the seen particle IV) The number of the molecules that are depicted is small, and may create a wrong conception of space. Finally, V) in two applets (7%), we observe that there is either a periodicity or a creation of formations in the way particles move, and in another there are problems in the borderline cases, because of the limitations of the software. The sources of the applets in case b, reveal a greater variety, than case a, since they come from high schools, companies, universities and colleges

c) *The combination of both ways (case a, b) of representation*: in six applets (20%) there is a combination of both ways of representation. They depict not only the particles, but also their track. The problems we mentioned above still exist. In two applets though, (7%) the user is guided in order to recognise the difference between the representation and the actual phenomenon. Apart from one (3%) that has been created by a company, the others have universities as a source.

2.Whether interaction with the user exists:

a) *No interaction*: In some applets there is no interaction with the user (13%) or it is restricted to the possibility of stopping and restarting the progress of the phenomenon (10%).
b) *Restricted chance of interaction*: In several applets, (33%) there is interaction, since the user can repeat the phenomenon. This lays emphasis on the randomness of the phenomenon and on the fact that the phenomenon has a different development every time.
c) *Extensive interaction*: In the remaining applets (43%) there is interaction. The user can change some parameters and observe how this affects the phenomenon or he/she can go to a different level and to the representation of the Brownian motion's mechanism.

3. The existence of accompanying text: The role of the comments that accompany each applet is important:

a) *Without accompanying text*: In some applets there is no explanation or there are minimum comments restricted to the use of the applet (34%). This has as a result of making the study of the applet difficult and it increases the danger of creating misconceptions.
b) *Accompanying text which explains the phenomenon and its representation* (45%),
c) *Accompanying text which refers to the history of the subject*: In some applets (14%) there is the historical aspect of the subject, which undoubtedly is very interesting, because it reveals basic characteristics of the scientific activity.
d) *Accompanying text which lays emphasis on the physics of the phenomenon*: Some other applets deal with the physical side of the subject and with the factors that affect the phenomenon (21%), (e.g. particles' mass, temperature, etc.)
e) *Accompanying text which recommends ways of using the applet and the phenomenon depicted in science classroom*: In two applets an educational approach is attempted with questions which are progressive and reveal the phenomenon step by step (7%), and
f) *Accompanying text which refers to the extensions of the phenomenon*: In one applet (3%) there are also some extensions that relate Brownian Motion to the stock market.

4. The variety of the ways the phenomenon is represented at the same time. In a lot of applets, Brownian Motion is presented multimodally, using more than one way of simultaneous presentation:

a) *One level of representation*: In most applets (50%) there is only one level depicting the phenomenon,
b) *Two levels of simultaneous representation:* In a lot of applets (34%) there are two levels: I) Observing each particle distinctively and the total distribution (10%), II) Observing the track and either the graph of position-time (7%) or a different graph (3%) at the same time III) Or, finally, observing the motion of the particles and explaining the phenomenon at the same time (17%).
c) *More than two levels of representation*: In four applets (13%) there are more than two levels of representation. Specifically, in one apart from the representation of the particles and their tracks, the velocity distribution for each particle is presented. In the second, we observe the motion of a particle in a fluid, its track and at the same time, the mean square displacement of the particle is estimated, allowing the verifying of Einstein's equation. In the third the motion of a pollen of grain performing Brownian Motion, is represented, the explanation that Einstein gave appears and, at the same time, more molecules of the fluid and the relative graphs are presented. Finally, in the fourth, only one level is presented,

but there are multiple pictures, which provide an educational approach to the subject, since they progress step by step.

5. The extensions that this phenomenon has in other areas:
   a) *Randomness and fractals*: An interesting aspect is the fact that some applets (14%) offer an attempt to stress the "special" randomness that governs the phenomenon, searching for regularities and referring in this way to the fractals.
   b) *Randomness and stochastic processes or economy*: Some others combine the phenomenon with stochastic processes (7%) or with financial parameters (3%).

CONCLUSIONS-SUGGESTIONS

The research of applets regarding to the way Brownian Motion is represented, pinpointed two main directions, which express in a relative way the epistemological and instructive views of their designers / creators. So, it evolved that mostly they choose: a) Either the specific representation of the particles, which participate in the phenomenon (e.g. spheres for the particles), b) or the more abstract representation (e.g. representation only of the tracks of the particles). The first one visually appears to be friendlier and more comprehensible for the students, so it can be used for the educational procedure. At the same time, though, it is not exact according to the valid scientific model, reducing its exploitation. The second one has no scientific problems, but there are restricted possibilities to its use in the educational procedure, mostly as far as high school is concerned.

Still, there is no doubt that Internet provides unique chances to observe the development of the phenomenon of Brownian motion, since it can reproduce the random movement of the particles. Moreover, it can contribute to the qualitative approach of the phenomenon, through the representation of the entities of microcosmos, which cause this motion. So, particularly in the case of Brownian Motion, Internet seems to be a dynamic means with unique possibilities, surpassing the possibilities of every school book.

However, imagery, which is included in every representation, is structured around its own rules of multimodal semantics, not necessarily accessible to every user. For this reason, not only the designer, but also the mediator of knowledge (teacher) ought to know how the receiver-student will "read" the imagery. Each representation is an attractive and complicated instrument but one which demands great attention when it is used. Only in this way can it be proved effective in everyday educational procedure. (Halkia et al 2002)

As a result, the teacher has to work and choose with a great attention the applets he/she will use. Moreover, every representation should be used in proportion to the students' knowledge and level. It should also make possible foe each student to be able to discriminate according to his/her abilities and experiences.

Furthermore a lot of representations exist which lay emphasis on different aspect of the phenomenon. It is essential to clarify the fact that every representation augments the total impression and the mental images the student will form. So it is important to the educational procedure to use more than one applet, after a close consideration of its role and the goal it will fulfill. Only in this way will it become possible to exploit the existing variety on the Internet.

There is the latent danger to convert the observation of the applet and the interaction that it usually contains, to a game for the students. In this case students concentrate on the possibility of altering the parameters which affect the phenomenon. At the same time they observe how this affects the progress of the phenomenon, in order to arrive at their conclusions. This problem, which is frequent in the classroom can be overcome if the teacher has planned his/her teaching carefully and if he/she has clear teaching goals.

In addition, the role of the text which accompanies the applet seems to be important. Specifically, the text should give clear directions for the use of the applets, to promote the

activation of the student / user and to direct him / her towards the comprehension of the phenomenon. This can be achieved mostly when the text suggests an active and not a passive role, making the receiver interact with the applet and inviting him/her to a stimulating dialogue. This should exercise the student's mental skills. (Theodoridis et al 2001)) The interaction, though, is also determined by the representation which has been chosen in every case. As is clear, the user can interact in a different way when the particles are represented, from when there is only their track.
The role of the accompanying text is important when it refers to the historic side of the subject. For example, the student can realise from the relevant text and the representation, that Einstein was the person who explained the phenomenon, but he is not famous for it. In this way a student may realise that a scientist may carry out multiple and important activities in scientific research, without becoming famous to the general public. This is something that depends on a variety of social and cultural factors. The students may realise in this way the procedures of scientific and research activity.
Another factor we should take into consideration is the limitations the computer imposes. The programs try to represent reality, but they do not always succeed in it. This is why we should use applets critically , all the while checking constantly their results in the educational procedure.

REFERENCES

1. Clinch, J. & Richards, K. (2002), *How can the Internet be used to enhance the teaching of physics?,* Physics Education 37(2), p. 109-114.
2. Hadzidaki, P. Kalkanis, G. & Stavrou, D. (2000), *Quantum mechanics: a systemic component of the modern physics paradigm*, Physics Education, vol.35, no 6, p.386-392.
3. Halkia, Kr. and Theodoridis, M. (2002), *The use of image in Science school textbooks: a system of classification and evaluation images*, Themes in Education, Leader Books, vol.3, no1, p.79-95.
4. Halkia, K. Tsakonas, P. Kalkanis, G. (1997) *A Study of Teaching Effectiveness of an Educational Monte-Carlo Computer Program simulating Buoyancy*, Proceedings of the GIREP-ICPE International Conference: "New ways of Teaching Physics", (21.8. - 27.8.1996, Ljubljana, Slovenia) p: 240-242.
5. Kostopoulos, D. (2002), *Physics Thermodynamics through Microcosmos,* Athens: Atrapos, p.171-172.
6. Lee,Y.K & Hoon,K. (1995), Brownian motion the research goes on…, http://www.doc.ic.ac.uk/~nd/surprise_95/journal/vol4/ykl/report.html
7. Serway, (1990) *Physics for scientists & Engineers,* vol.3, Thermodynamics-wave physics-optics, 3rd edition, Saunders College Publishing, p.77
8. Stylianidou,F. and Ormerod,F. (2002) Analysis of science textbook pictures about energy and pupils' reading of them Int.J.Educ.,2002,vol.24, no3, p.257-283
9. Theodoridis,M. & Halkia,Kr. (2001), *Latent aspects in science textbook pictures" (Poster). Proceedings of the Third International Conference on "Science Education Research in the Knowledge Based Society*, organized by ESERA (European Science Education Research Association). August 21st- August 25th, Thessaloniki, Greece, vol.2, p.850-852.
10. Trikalinos, C. (1996), *Molecular Physics Thermodynamics,* 2nd edition, Athens, p.110-111.
11. Young,H.D. (1994) *Academic Physics* vol. 2, Electromagnetism-optics-Modern Physics, Addison-Wesley Publishing Company, 8th edition, Athens: Papazisi, p.1148-1149

Kyriaki Dimitriadi & Krystallia Halkia
Department of Education (P.E.)
University of Athens
Navarinou 13A
10680 Athens
Greece
kdimitr@primedu.uoa.gr, kxalkia@primedu.uoa.gr