Newton-3 : A Software For Teaching Dynamic Interactions.

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Abstract. *The educational software presented in this work, is a web-based application, designed for the topic of 3rd Law of Newton. The software covers a series of several cases from gravitational interaction to electrostatic. The software sets a series of 11 "Lab" activities, and in each Lab, students are given a problem of interaction and are asked to place the forces. The software is structured on an interactive dialog-basis, where a pictorial "expert" changes faces and makes comments upon students' response. Cases examined in the "Labs" and expert's comments are selected on the basis of students' conceptions. Each "Lab" consists of subsequent steps, where students are gradually introduced from the concept of "one body exerts force to the other" to the concept of "mutual action". In this work we present the design of the educational software developed. Some preliminary results on the logging capabilities of the software are also presented and discussed in brief.*

Keywords. Educational Software, Newton's 3rd law, Teaching, Web application

1. Introduction

The 3rd law of Newton and the concept of interaction between objects are two key points of prime significance to the construction of concepts related to situations of objects' motion, equilibrium and change of kinetic state [1,2]. Despite the significance of the topic, and even though advances in ICT have been widely acknowledged to promote a more efficient teaching and learning, very little attention has been given in the development of appropriate software in the case of Newton's 3rd Law. In the majority of software available, the topic of Newton's 3rd Law is covered as a part in a larger piece of software, usually connected with kinematics and free-body diagram representations. In most of the cases, interacting forces can be shown as arrows on the click of a button. In other, yet fewer, cases of educational software, the user (student) is given with a picture of "interacting" bodies and pairs of forces, as pairs of arrows of similar size and opposite directions, and is asked to "place" them on bodies [3]. Though either of the approaches – visualization of both arrow-forces on the click of a button or placement of a pair or arrow-forces– might be advantageous in many cases, however, they may hardly elucidate the essence of "interaction" in the sense of a mutual relationship and a mutual action between two bodies.

The educational software presented in this work, is a web-based application, designed for the topic of 3rd Law. The software covers a series of several cases from gravitational interaction to electrostatic. The design is based on a recent literature review[4] and empirical research[5] which reveal that students usually consider force to be either an internal or acquired property of a body rather than an outcome of the interaction between the bodies; for example student-teachers still tend to share the opinions of a "give" rather than "exert" force model [4].

The software sets a series of 11 "Lab" activities, and in each Lab, students are given a problem of interaction and are asked to place the actions. The software is structured on an interactive dialog-basis, where a pictorial "expert" changes faces and makes comments upon students' response. Cases examined in the "Labs" and expert's comments are selected on the basis of students' known alternative conceptions. Each "Lab" consists of subsequent steps, where students are gradually introduced from the concept of "one body exerts force to the other" to the concept of "mutual action".

2. Visual description and use

Newton-3 application runs on a simple web browser with Macromedia Flash plug-in installed. The main screen looks like a notebook page, and is divided into two main sessions. The left-most part is the actual application, called a ‘Lab’. Each ‘Lab’ consists of different activities-tasks, as described below. The right-most session (see Fig.1) is text area, which contains brief instructions for ‘Lab’ activity, to run. Text is kept to a minimum and briefly describes the tasks that the student (user) has to do in each ‘Lab’ activity. User (student) may select among a total of 11 different ‘Lab’ activities from the menu-like buttons at the bottom of the html page. User instructions appear as a pop-up window, on the click of ‘instructions’ link.

Figure 1. Main screen of the application.

A typical ‘Lab’ stage is shown in Fig.2. The stage is divided into 3 parts; the main part is devoted to the visual representation of the interaction addressed in the ‘Lab’ activity. The right-most part is a tool-box, and the bottom part is the ‘experts comment’ on student’s actions. A photo-realistic representation both of the background and of the interacting bodies is adopted, to help the user (student) to get a clear view of the problem presented. In figure 2, the case of ‘earth’ and ‘moon’ is presented, while background is set to represent the ‘universe’. User is asked to pick and place the action that one object (ex. the ‘earth’) exerts onto the other (the ‘moon’). The action exerted, is represented by a vector (arrow). The arrow -force vector- is initially placed at the ‘empty space’ between the two interacting bodies and the user is prompted to set the vector at the ‘proper’ place. Student may place the force vector by direct manipulation on the arrow representation (drag and rotate). The angle of rotation is set on the ‘Rotation-disk’ (abstract representation of a protractor) in the toolbox.

Figure 2. Typical ‘Lab’ stage : the case of the Earth and the Moon.

Visual representation of the ‘Lab’ can run into two modes: either in a photo-realistic representation, or as abstract schematic (Fig. 3). The ‘schematic’ button in the toolbox does toggle between the two modes of representations.

A time indicator located within a schema of an apple-like outline displays the time elapsed since the start of ‘Lab’. It serves as a visual indicator for the student to monitor the time required to makes his/her choice and place the arrow-vector. Then, student should press the ‘check’ button to get a comment on his/her choice. The ‘expert’ at the bottom part of the screen, changes faces as a visual indication to his satisfaction on student’s try out, and gives a prompt on what student should take into account to get a better result. The apple-like outline is gradually filled up on incorrect answers.

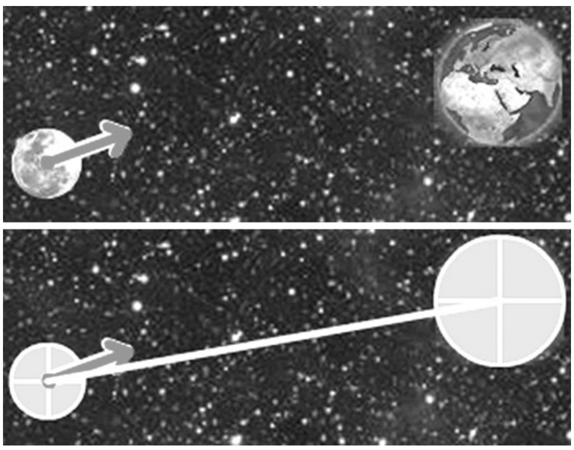

Figure 3. Photo-realistic and schematic mode of representation

2.1. Interactive dialogs

One of the most important parts of this software application is the feature of the pictorial expert that can serve as a virtual "teacher". On one hand this feature is used to supply the student with the initial (kickoff) instructions regarding the task at hand and what must be done. For example:

> *"In this Lab we shall study the action that the Earth exerts onto the Moon. You should place the action (vector) of the Earth on the correct spot."*

On the other hand every time the program goes through a check on student's answer (by a click on the "check" button) the system feedback appears in the "expert respond" area. The responds are not just a simple indication of error but aim to help the user to understand the problem and, at the same time, to prompt for the right direction of thinking. For example in the case that the student has placed the tip of the arrow-vector on the surface of the correct body (i.e. moon), the 'expert' will respond by:

> *"The vector depicts the action of the one body (Earth) on the other (Moon). You have placed the tip of the vector on the surface of the Moon. Remember that the vector is applied on the centre of mass to the body that acts upon. Try again."*

Or, in case that the student has placed the vector in the correct spot but pointing to the wrong direction/angle, the "expert's respond" would be:

> *"The vector depicts the action of the one body (Earth) on the other (Moon). You have placed the vector's point of application on the centre of the moon. Remember that force is a vector, and direction is one important element to a vector. Try again"*

2.2. Program feedback and checks

Several cases of possible student's answers in placing the arrow-vector are examined. Cases setup a dataset in the form of a look-up table, based on known students' alternative conceptions on vector representations, force as a vector, and on interactions on the 3rd Law of Newton [4,5,7,8]. The program runs the checks starting with the vector's base (point of application). The several cases examined are outlined in Fig. 4:

In reference to fig. 4, the following cases are examined:

I. The force-vector is applied on neither of the bodies but on the 'empty space'

II. The force-vector is applied on neither of the bodies but is much closer to one, the wrong one.

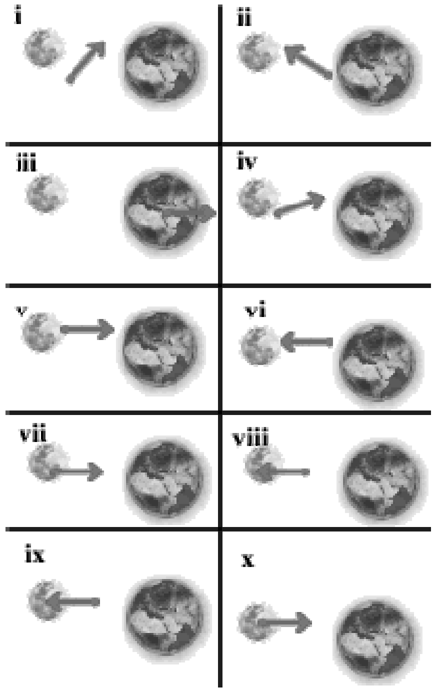

Figure 4. Check on different cases representing the action of one body (Earth) onto the other (Moon)

III. The force-vector is applied on the wrong body.

IV. The force-vector is placed close to the correct body.

V. The base (point of application) of the force-vector is placed on the surface of the correct body.

VI. The tip of the force-vector is placed on the surface of the correct body.

VII. The base of the force-vector is placed somewhere on the correct body but not on the center of mass.

VIII. The tip of the force-vector is placed somewhere on the correct body.

IX. The tip of the force-vector is placed on the center of mass.

X. The base of the force-vector is placed on the center of mass, and this case the direction of the force-vector is examined.

3. Description of the Lab activities

Each 'Lab' activity is divided into four sessions, as outlined bellow. Each session follows the previous one, upon successful completion. The first two sessions, deal with the problem of <u>*one*</u> body acting onto the other, while the last two sessions deal with the bodies interacting. The essence of "interaction" in the sense of a mutual relationship and a mutual action between two bodies is introduced, after students have thoroughly examined the concept of 'action'. In more detail,

i) On the first session (Fig.5a) the student is asked to place the <u>*action*</u> of the one body (right) to the other (left). Much emphasis is given on the student's understanding on the representation of the action as <u>*force*</u>, and the vector characteristics of force.

ii) Second session (Fig.5b) is similar to the first one. The term of <u>*reaction*</u> is introduced, as the action on the other body exerted onto the first. Again, the main focus is on the student's understanding on the characteristics of force as a vector. Students are asked to deal with a similar problem (as in the 1st session) and this similarity is believed to help them set the basis for the understanding the mutual relationship between <u>*action*</u> and <u>*reaction*</u>.

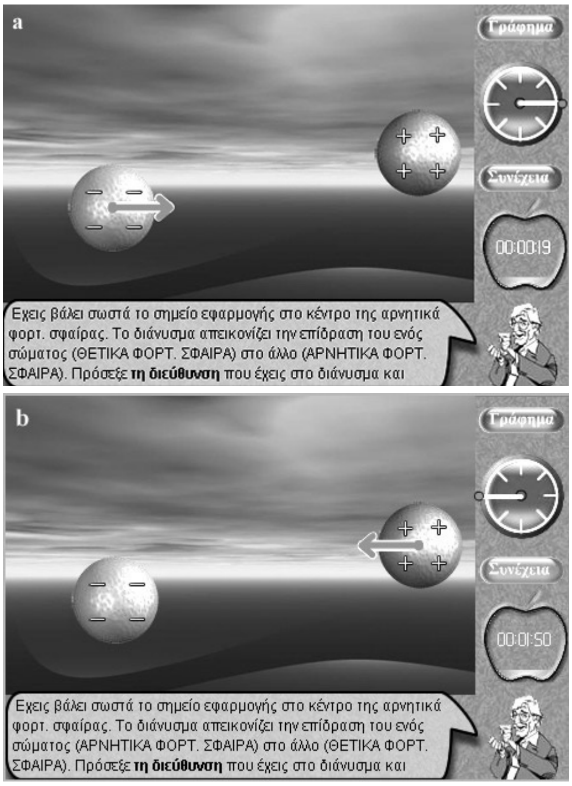

Figure 5. Action and Reaction in the case of two charged bodies: student tryouts to place the *action* (a) and the *reaction* (b).

iii) Third session (fig. 6a) explores the concept of "mutual relationship". The session summarizes the activities of the previous two sessions into a unified set. The student is asked to place both forces on the two interacting bodies. The concept of *"equal in magnitude but opposite in direction"* is explored.

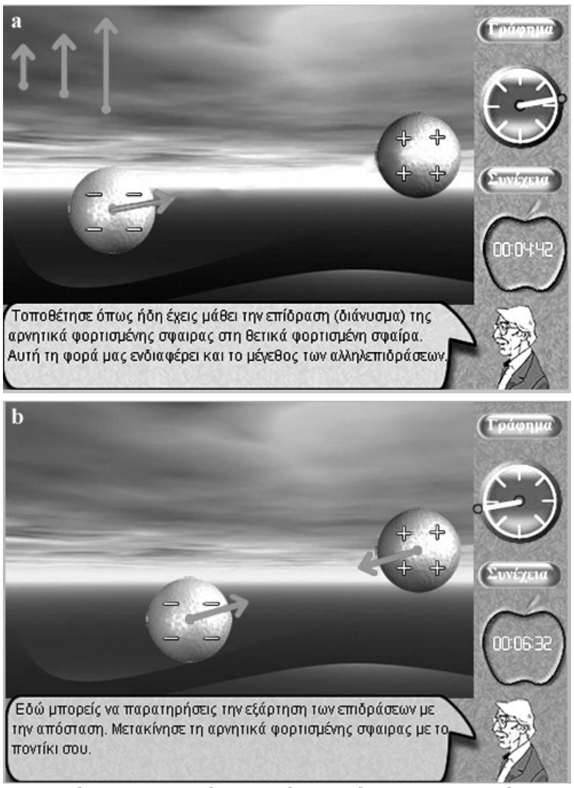

Figure 6: Action and reaction as mutual interaction. (a) Student is asked to place the reaction on second body and (b) to move one of the bodies and observe the mutual change in action-reaction vectors.

iv) The concept of mutuality is further explored in the final (4th) session. The session is an interactive simulation (fig. 6b), where the two bodies are shown interacting, and the force-vectors appear on each of the bodies. The students are asked to drag one of the interacting bodies all over the screen and observe the two force-arrows, changing in magnitude simultaneously and always pointing one against the other (opposite directions).

3.1. Lab activities in different fields

This application consists of 11 'Lab' activities grouped into two general categories of objects' interactions: gravitational and electro-static. The general structure of each 'Lab' is the same with the one we described above. The choice of these two general categories and of the specific labs was based on the step-by-step progress of the examples from the more familiar to the more complicated. The aim is for the user to be able, after the competition of the series, to appreciate the generalization of Newton's third law. The cases examined are based on students known learning difficulties, where students tend to explain the interaction between two bodies by adopting a ‘dominance principle’; i.e. the greater mass the body has, the greater the force it may exert[4,5,9-11]. The 11 ‘Lab’ activities are listed bellow:

1. Gravitational interaction between two celestial bodies: the case of Earth and Moon
2. Gravitational interaction between an object of everyday use (ex. apple) and the Earth. Both are considered as free in the space
3. Gravitational interaction between two objects of everyday use, as two free objects in the space
4. Gravitational interaction between two objects of everyday use when they are close to the surface of the earth
5. Gravitational interaction between two objects of everyday use, when they are inside a room
6. Electrostatic interaction between two metallic spheres that have the same positive charge but different size
7. Electrostatic interaction between two metallic spheres that have the same negative charge but different size
8. Electrostatic interaction between two metallic spheres of the same size and opposite charge of equal value
9. Electrostatic interaction between two metallic spheres of the same size and opposite charge of unequal value
10. Electrostatic interaction between two metallic spheres of different size and opposite charge of equal value
11. Electrostatic interaction between two metallic spheres of different size and opposite charge of unequal value

4. Activity Logging

Newton-3 application is capable of activity logging. Activity logging takes place when application runs in a client-server mode. Activity logging is a text file, comma delimited, so it can be easily processed and analyzed. An extract of a typical Activity logging file is presented in fig. 7. Figure 7 shows the activities of a student in the case of two spheres interacting electro statically (Lab 8). The student is prompted to place the vector indicating the *action* of one sphere onto the other (Serion_1 in Lab8). Student’s recorded actions are indicative to his/her conceptions and could elucidate his/her pattern-of-thinking. The first steps in the Fig.7 could show a ‘give force’ thinking model, rather than ‘exert force’; the student tries to place the vector (action) on -or around- the body which, as quoted in the text, is the acting body. Next steps elucidate the student’s conceptions on force as a vector representation; the student, in his/her successive trials, places the arrow-vector pointing to the center of mass, or to the surface, sets the vector inside the body but not on center on mass, etc.

```
Lab_8,  Session_1,  00:00:22,  Action:  The
vector is on the free space.

Lab_8,  Session_1,  00:00:26,  Action:  The
vector is set on wrong body.

Lab_8,  Session_1,  00:00:33,  Action:  The
vector is set on wrong body.

Lab_8,  Session_1,  00:00:38,  Action:  The
vector is set close to the wrong body.
. . . .
Lab_8, Session_1, 00:01:46, Action: Correct
body, arrow points to CM

Lab_8, Session_1, 00:01:49, Action: Correct
body, arrow points to surface

Lab_8, Session_1, 00:02:09, Action: Correct
body, arrow is inside the body
 . . . .
```

Figure 7. Extract of Activity log file

Thus, using *Activity Logging* one may educe valuable conclusions regarding the original students’ views on interactions, how views may develop as the student advances from Lab activity to another, whether student might develop a strategy from one activity to another, etc.

5. Concluding remarks

The *Newton-3* application is a Web based application, accessible through any typical browser with the Macromedia Flash plug-in. The applications sets a series of 11 ‘Lab’ activities, based on students’ conceptions on the 3rd Law of Newton. User-friendly principles taken into account [12], easy of use and sound pedagogy make it a useful tool for the introduction of the concepts of “mutuality” and the essence of “interaction”.

The application design is fully modular, adaptable and expandable (fig. 8). Comments and ‘expert’ prompts are not hard coded in the program but they are found in a single external text file, which acts as a source. This way, even an individual instructor can adapt and also translate *Newton-3* without any programming knowledge. The application is easily expandable to other types of interactions (eg. magnetic interactions), since pictures are also external graphic objects assigned to program internal variables. Program functionality, feel-and-look and even the activity logging option and data formatting are also defined in external text-files.

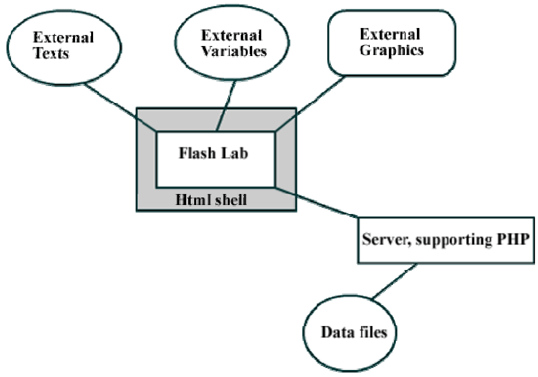

Figure 8. The structure diagram of the application.

Though *Newton-3* can run as a stand-alone web application in a typical PC, a client-server scheme is required for *Activity Logging*. Modern USB and mini-server technology can make *Newton-3* run at full activity logging functionality, in a typical school computer-lab, through a low cost USB-stick, on which a php-supported http minimal-server set running. These capabilities open new dimensions in the evaluation of students' responses to the 'Lab' activities. It would be quite interesting to investigate the development of patterns-of-thinking on individual user-student basis. This work is currently in progress.

6. Acknowledgments

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7. References

[1] Hestenes D, Wells M, Swackhamer G, *Force Concept Inventory*. Physics Teachers, 30, 141-158, 1992.

[2] Ioannides C, Vosniadou S,. *The changing meanings of force*,. Cognitive Science Quarterly, 2 5-62., 2002

[3] Kolkotronis D, Solomonidou C, *Students' conceptions about mechanical interaction and design of appropriate educational software for constructive teaching*. in Psillos D, Kariotoglou P, Tselfes V, Bisdikian G, Fassoulopoulos G, Hatzikraniotis E, Kallery M (eds), *Proc. of 3rd Intern. Conference of ESERA*, Thessaloniki, 2001.

[4] Kariotoglou P, Kounatidou C, Karnezou M. *A review of pupils' conceptions concerning force.* in Tselfes V, Kariotoglou P, Patsadakis M. (eds) *Teaching, Learning and Education in Science*. Proc. of the 4th Hellenic Conference for Science Education and New Technologies, Athens, 2004.

[5] Kariotoglou P, Spyrtou A, Tselfes V *Student – teachers' conceptions about gravity interaction*. accepted for publication in the proceedings of the 5th ESERA conference. Barcelona, Spain, 2005.

[6] Kariotoglou P, Spyrtou A, *A Teaching – Learning sequence concerning dynamic interactions:the need for appropriate software* 2005 (in this volume)

[7] Palmer D. *The effect of context on students' reasoning about forces*. International Journal of Science Education, 19, 681-696, 1997

[8] Erickson, G.L, Aguirre J. *Students' intuitions and science instructions: Stability and task context in students' thinking about vector quantities*. Annual Meeting of the Canadian Society for the Study of Education, Montreal, 1985

[9] Viennot L, Spontaneous reasoning in elementary dynamics, European Journal of Science Education, 1, 205-221, 1979

[10] Maloney D.P, *Rule governed approaches to physics-Newton's third law*, Physics Education, 19, 37-42, 1984

[11]Brown D, Clement J. *Misconceptions concerning Newton's law of action and reaction: the underestimated importance of the third law*, in J.D. Novak (ed.), *Proc. of 2nd Intern. Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, Cornell Univ, 3, 39-53, 1998

[12] Mikropoulos T, *Educational software: Issues on the Development and Evaluation of Hypermedia Software*, Kleidarithmos Pub. 2000, (in Greek)