Interactive Education Based on Haptic Technologies and Educational Testing of an Innovative System

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Abstract—This work presents on the one hand, the specifications and design of an educational haptic device and an educational platform and on the other hand, the educational trial of the applications that specially constructed in order to use this advanced virtual reality system. A new haptic device designed especially for educational purposes and a prototype were implemented, under the framework of an IST European program called MUVII. This device is called Haptic-3D-Interface (H3DI). The novelty on this device is the tactile feedback that provides minute detailed information about the nature of virtual objects handled, in addition to force and torque feedback. The device was integrated into an innovative platform called Interactive Kiosk Demonstrator (IKD). IKD's aim was to demonstrate new interactive paradigms forming a novel integration of the following modalities: 3D-vision, 3D-audio and haptic (force, torque, and tactile) feedback. Besides, interactive educational software especially designed for IKD platform was developed. Then the educational trial of the IKD system, as well as the educational software, took place. All schools that participated in the trial were randomly selected. A total of 163 students participated in the educational trial, 64 of which were primary school students, 74 were lower-secondary school students, and 25 were upper secondary school students. For the educational trail all the international accepted practices concerning research in education were followed. The "exercises" for each group of students were chosen in accordance to their age. The educational results of this teaching approach, as well as the feedback derived from the users are presented in this work. Furthermore, some interesting results concerning important requirements for the specifications for haptic devices are also presented. Overall, we can state that the opportunity of having a natural "look and feel" environment for teaching purposes proves extremely promising.

Index Terms—Constructivist Theory, Haptic interfaces, Science Education Applications, Virtual Reality.

I. INTRODUCTION

Science and technology are omnipresent in everyday life and they play a very important role in today's culture. Students should learn science for many reasons but the most important one is because the economic strength, the progress and the wealth of all modern societies is based on Science and Technology. After all, only with Science can the world go on. In all its aspects, (Medicine, Pharmacology, Chemistry, Computer Science, Biology, Physics). Science tries to expand human understanding about the world, and to improve the quality of life. If it was not for Science, the earth could not feed or warm its population, and in any case, life would be much harder in general.

Therefore education should, also, aim to attract a greater number of young pupils to study science, so as future scientists and engineers emerge from them [13].

Despite its immense importance, primary school teachers are afraid to teach science, and even more so to use the school science laboratory [6].

Research has shown that science is the most difficult, most time consuming and least interesting subject especially amongst older students. Research has also confirmed something that all active teachers already knew: students come to school with different knowledge and skills, and not all students have the same interests, and abilities. Although all children follow the cognitive development stages as these are described by Piaget [10], the age that students reach each stage varies substantially. Individual learning has always been considered an important requirement for education. While nowadays some new parameters were added: students should acquire collaborative and self-learning abilities. Both requirements can only be achieved with great difficulty in traditional classes, where all students had to follow the same curriculum, and where the teacher normally follows the chalk and blackboard teaching approach.

The various advantages of using ICT in education have been explained by Garyfallidou and Ioannidis [5][6]. Such arguments remain largely unaffected by changes in ICT. However, a growing number of schools in Europe already have (or will soon have) modern computer labs and broadband access to the Internet, enabling them to take advantage of multimedia resources and new interactive learning methods using web-streaming [7]. Seen from a technical point of view, ICT education starts being implemented with a sequence of well-designed web-pages or some lines of code. Seen from an educational point of view, ICT education is a rapidly changing field, because technology changes extremely fast and this, results to changes on ICT education. Research done over a decade ago, should now be considered obsolete because new computers are so much different from the previous ones. Furthermore, new parameters and increased ICT capabilities have not been considered by older research, and start appearing now. Screen analysis, quicker processors, much better internet connection speed, e-learning environments, and now inexpensive haptic devices and streaming media delivery.

II. THE ADVANTAGES OF USING THE COMPUTER AS A TOOL IN ORDER TO TEACH SCIENCE

Educational software could come as an invaluable help to teachers trying to teach Science. The use of the program can speed up considerably the teaching process (as opposed to a real experiment), and given the time limitations, the whole of the curriculum could be covered. The design and implementation of any computer-based learning environment be that educational software, streaming medium, or web based material, should follow some concrete steps. These steps have been described in detail by Ioannidis et al [7] and are reported here briefly:

1. The educational target should be specified. The curriculum that is going to be the subject of the medium should be defined clearly and specifically. The cost of the streaming medium, the time spent fir it to be developed, and the time that it will remain in use should be specified in this step.

2. At the second step, we must gather every piece of information relative to the subject.

3. The third step demands the co-operation of the computer experts, the expert on the subject (e.g. scientist), the education specialist of the subject, and some ordinary schoolteachers. The expert specialist will define what should be included in the medium. The education specialist will define the way the subject should be presented to the student. The teacher will tell if he is in need of the educational environment, if it is user friendly and easy to use, and if he can use it creatively.

4. The team of programmers tries to put into action whatever has been decided in the previous step. It is suggested that a rapid prototyping method should be followed. The prototype would highlight the function of the program.

5. The full team of experts should evaluate the prototype of the environment, and if it is necessary certain changes and improvements are specified.

6. The educational environment is produced.

7. The final educational evaluation is taking place as well as the quality assessment of the environment [14] against specialized metrics based on the four external quality characteristics (functionality, usability, efficiency and reliability) of the ISO9126 standard for software systems.

In a computer based learning environment implemented using the above mentioned steps, texts contained as well as definitions, videos or simulations are scientifically correct. Apart from the scientific correctness, the use of such an environment in the teaching and the learning process has many advantages compared to the traditional teaching. These have been described elsewhere by Ioannidis and Garyfallidou [5]. Here we will only mention the most important ones.

1. A computer-based educational environment can be used for "individual teaching". Every student learns following his own pace.

2. It allows us to differentiate between the time a subject is taught and the time it is studied and learned.

3. The communication between "the computer teacher" and student is immediate and full duplex.

4. The student learns by self-action instead of passively hearing the teacher teach.

5. It allows equal opportunities to all children, since everyone can reach the best teacher, the well-organised library, the physics laboratory, or the chemistry laboratory (simulation).

6. We can simulate experiments that are difficult or even impossible to take place in the classroom. This is the case with haptic interfaces. Friction is a typical example of a physical quantity responsible for common failures of experiments in school-labs. Computers can easily "switch off" friction of any type or form. The computer can (for example) simulate the gravity forces of the planets on a spacecraft or follow the free fall of objects. We can change parameters such as the acceleration of gravity and see the effects this change has in our experiment, or emulate energy transformations in a virtual house.

7. Finally yet importantly, children, especially the younger ones, adore playing with computers. They like to use a tool that belongs in the "adults' world", a machine that does not break down, and which is very patient with them.

III. HAPTIC (FORCE, TORQUE, AND TACTILE) FEEDBACK FOR EDUCATION

Traditionally most of our daily activities were accomplished by the use of the human hand. Computers may have brought significant changes to our daily life but the interface is still carried out through a keyboard and a mouse which are data input devices, that do not offer to the user any information related to the "object" he/she manipulates, and this is equally so even if we speak about virtual reality. Any human - computer interaction is carried out through traditional peripheral data output devices, such as a screen. The computer responds to the data input made by a keyboard or a mouse (manual input) with data sent to the screen. Computer never sends data to the keyboard or the mouse because these could not create haptic reaction to the user's hand. Haptic devices come to eliminate this limitation.

"Unlike traditional interfaces that provide visual and auditory information, haptic interfaces generate mechanical signals that stimulate human kinesthetic and touch channels. Haptic interfaces also provide humans with the means to act on their environment." [4].

A purely audio-visual environment, even if it is highly interactive, can present difficulties for "haptic learners". By addressing the sense of touch, haptic interfaces are promising tools for helping students with haptic cognitive styles obtain an understanding of mathematical and physical phenomena [9].

When a student uses haptic devices receives two kinds of stimulants, distinguished in kinesthetic and tactile perception. The kinesthetic stimulants refer to (process without the use of haptic information) the user's ability to self-define his body position as well as his movement and weight, and they are the result of either three dimensional forces which act upon the body (resulting to body movements, for example, hands) or to tendencies (again three dimensional forces that now result in member or

body rotation). Tactile perception derives mainly – but not exclusively – from touch (pressure sense) with the fingertips. It is experimentally proved that where vision is the dominating sense in form perception (macro-geometry) of bodies, touch excels in defining their texture (micro-geometry). For more information to this subject see Ref. [12] and Ref. [8].

Haptic stimulants are dynamic, which means that they change as the user is operating the objects, no matter if they are physical or virtual. The term tactile is used primarily in referring to passive touch (being touched); but haptics involves active touch such as a student manipulating an object during hands-on science explorations. This active touch involves intentional actions that an individual chooses to do, whereas passive touch can occur without any initiating action, as stated at the web site of NanoScale Science Education Research Group [17].

Although the technology related to the sense of touch exists for decades, the existing systems that can be used for educational purposes are still very expensive, complicated and their use is focused not so much on education but on professional instruction [4], as for example in professional flight simulators in a specific aircraft type (with a cost exceeding that of the aircraft itself), or even for medical instruction in using specific apparatus like a remote operation or a laparoscopisis. The specific professional simulators are based on the principals of consistent mechanical representation of the device that is being simulated, as in the actual movements of the mechanical parts that constitute them through dedicated servo-mechanisms. From the control motion or even the floor where the trainee is positioned, derives the sense of touch for the user, simply as a reaction produced on the fingertips from the motion of the controls or on the whole body from the inclination of the seat (due to gravity) or from the acceleration of the simulator's floor.

Research has been carried out, studying the relationship between training technologies (computer and print) and individual learner differences (visual and haptic cognitive styles), in assisting learners' retention of information presented visually [2]. Research on the educational issues is significantly more complicated due to problems rising from the teaching approach parameter, and therefore has to wait for the development of a new type of haptic systems more suitable for general education.

It is obvious that the "traditional simulators" us the ones described above have no future in general education. To start with, there is the matter of high cost. Although these devices are controlled by a series of powerful computers, the cost of which goes down by the time, the electro-mechanical nature of the interface which varies according with the device simulated, should be build, which raises the cost of the construction extremely. Any effort to use this old type simulating devices to general education, would lead to the development of many different and totally independent devices each one of which simulates only one very specific experiment of physics. This would not only be economically unfeasible, but also undesirable for education. This is because this is not the case of a MBL (microprocessor based laboratory) where there are physical objects that the student is manipulating, and where only the data collection and processing is done by microprocessors. On the contrary the above mentioned simulations are deprived of adaptability. It is hard, for

example, to imagine the simulation of a school laboratory for electricity experiments (where the student can make a false connection and learn from his mistakes) using an old type simulator. This is because its reduced flexibility, which prevents it from simulating adequately the student's fault case.

Inevitably this results to simulating the lab, using software, which is complete and flexible, but it lacks haptic feedback as moving and connecting the various virtual units is done using the PC mouse. Flexibility raises difficulty as well. Instead of having specific levers and joysticks (as in traditional simulators) here the sense that the user feels while touching an object should be simulated.

Despite the difficulty in creating this kind of devices, this was exactly what the research team of MUVII achieved. An input-output data feedback device was created, which apart from creating three dimensional forces and torques (which is something rare), it also creates tactile stimulants on the user's fingertips. In this way a full haptic feeling is created. In addition the designed device, is made for educational use and in particular for the creation of a virtual haptic physics laboratory.

IV.   MUVII PROJECT DESCRIPTION

MUVII stands for the *Multi User Virtual Interactive Interface* and is the acronym of the IST Project IST-2000-28463. The key objectives of MUVII project [16] were two. To, firstly, develop two new Man-Machine-Interface Devices featuring haptic feedback, called Haptic-3D-Interface (H3DI), featuring not only force and torque feedback, but also a novel *"surface of objects" tactile sensory activation*. Also, develop a prototype of an innovative integrated platform using these haptic devices: This was called the Interactive Kiosk Demonstrator (IKD). The haptic device activates the sensors of pressure that are found in the endings neuron of the user's fingertips, lending to him, via the new sense (tactile feedback), an additional level of realism with regard to the natural features of the virtual objects that the user touches or moves. Additionally, the user can feel force and torque feedback directly on his fingers, when he tries to move or turn a virtual object, according to the size and weight of the object. Apart from the abovementioned haptic stimuli, the user of the IKD interactive environment also receives stereoscopic optical stimuli (3D-vision) and can understand the direction and the volume of the sounds around (3D-audio) by using special open-air headphones and head tracking mechanisms. University of Patras (HPCLab - High Performance Information Systems Laboratory) was responsible for the design and integration of the IKD platform as well as the development of the 3D haptic applications. In cooperation with The Science Laboratory of the School of Education of University of Patras, provided the specifications of the device and carried out the testing of the whole platform with pupils and teachers. The other partners of the project were: Laval Mayenne Technopole (France), CEA - Commissariat a l' Energie Atomique (France), SINTEF - The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (Norway), De Pinxi (Belgium), Institut für Kommunikationsakustik – Ruhr University of Bochum (Germany), ONDIM (France), CompuTouch (Norway), Centre PIC (Russia).

The opportunity of using a natural "look and feel" environment for teaching purposes is a very promising one indeed. The purpose of MUVII IKD was to demonstrate new interactive paradigms in a novel integration of the following modalities as these interfaced interactively with the user: *3D-vision, 3D-audio and haptic (force, torque, and tactile) feedback*. The process followed in order to design, implement, and test the IKD was:

1. *User requirements and constraints* for the IKD device and applications were gathered and analyzed.
2. *Technically feasible specifications* of the IKD device, applications and platform were defined in detail.
3. Design and development of the *IKD device*.
4. Design of the modular architecture of *IKD supporting platform*.
5. Design and development of *IKD Applications*.
6. *Integration of the hardware and software modules*.
7. *Educational Testing of the IKD*, for more than three months, with an adequate sample of more than 300 pupils, and some teachers.

In this paper, the six first stages are briefly presented, while the last one is described in detail. Several useful conclusions are drawn, which can be used as a useful guide for those interested in developing haptic interfaces and applications for educational purposes.

V. INVESTIGATION AND ACQUISITION OF USER REQUIREMENTS

In order to judge the pupils' reaction towards virtual reality environments involving haptic feedback interfaces, some trials were performed using both children (of various ages) as well as adults, and utilizing a setup involving commercial haptic interface devices (e.g. Phantom by SensAble Technologies, I-Feel-Mouse by Logitech). The results of those trials were most encouraging, especially considering that these devices have a "feel" a lot less natural than the one expected from the H3DI of the MUVII IKD.

After careful consideration of the educational needs, (particularly in the context of science education) the most important parameters of the requirements of the end-users were drawn up, and the functionality of the projected end-product was discussed with selected educational exponents (mostly teachers). The shape of the IKD device was defined after several discussions with potential users (mostly with teachers and to a lesser extent with students), and after taking into consideration the limitations of the new technology. The users were fascinated with the idea of using haptics in their classes since this technology gives the opportunity to observe, test, and simulate phenomena that due to several reasons could not be performed in a class or a school laboratory [5], or even impossible to be executed anywhere (like hypothetical experiments – Gedankenexperiment).

The most important of user requirements for the IKD device was the movement independence, the feeling of force feedback independently on each finger, the precision of the movement so that the haptic device could function "transparently" as an extension of the user's hand.

As far as the potential applications were concerned, the users described the most educationally preferable software as one that used a scenario that could not be easily performed in a class, but with a high educational value nevertheless, while being exciting enough to attract the student's attention. Many different ideas for educational scenarios were put forward and were exhaustively discussed.

VI. ANALYSIS OF USER REQUIREMENTS

In the ensuing analysis, it was revealed that as far as the device was concerned, users wanted to use advanced *wearable (not ground-based) haptic interfaces* instead of joysticks. The characteristics most users required involved *grasping, manipulating and throwing objects* in the virtual space, while feeling forces and tactile feedback on as many fingers as possible. The users required to be able to *investigate and explore* 3D objects and *feel* their material, surface, size, shape, etc. Another very important characteristic for the educational use of the IKD was deemed its *realism*. Special emphasis was paid in support of *accurate hand and finger movement*.

Considering the projected educational use of the device, users wanted an *"easy-to-use" device* that did not require in-depth knowledge of computers, robotics, or physics. Another important factor was the *weight* of the device – the need to be as light as possible so that young children can handle it – and the *freedom of movements*. The users wanted the device to be a "natural" continuation of their hand, which they can freely move and act in the application's environment.

Regarding *3D sound features*, users found very interesting the idea of hearing the various sound cues of the application and being easily able to perceive their direction, distance, and volume, while at the same time being able to communicate with the other users by using open-air headphones.

The analysis of the user requirements led to the specifications of the IKD haptic device, the IKD platform and the IKD applications, as described in the next sections.

VII. THE PROTOTYPE OF THE IKD HAPTIC 3D INTERFACE (H3DI)

The Haptic 3D Interface (H3DI) prototype (Fig. 1) was developed by project partner CEA. It is composed by two 3-DOF robots attached to the hand allowing finger movements without restriction (except that closing movements are limited to ~20mm aperture, due to the size of tactile motors). The force feedback on each finger was adjusted to 5N in all directions and the device's size was adjustable to hands of various sizes, an important feature, considering that children of various ages used it.
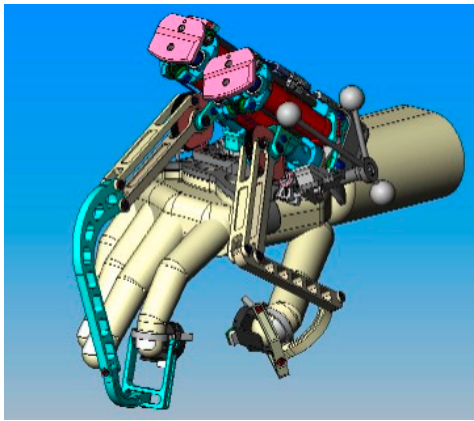
Figure 1.   IKD H3DI concept and realization respectively
(Courtesy of CEA)

Attached on the index and thumb fingers were two tactile motors (Fig. 2), whose function was to allow the users feel the surface contours and textures. Developed by CompuTouch, each one of them weighed 15gr, had a 20mm diameter, and was 15mm high. The integration on the H3DI allowed good force feedback on finger, while keeping fingertips free for tactile feedback.
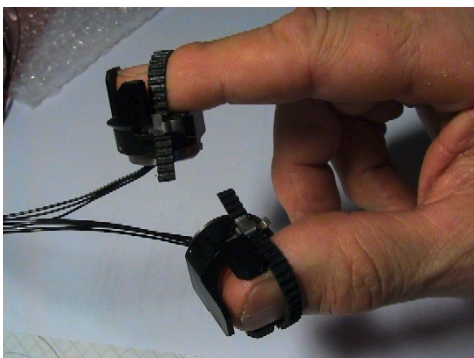

Figure 2.   Tactile Motors (Courtesy of CompuTouch)

VIII.   IKD PLATFORM SPECIFICATIONS AND INNOVATIONS ACHIEVED

Three modalities were involved in MUVII interactive environment: visual, haptic, and aural (i.e. sound). To achieve the best virtual reality immersion the best solutions for each one of these three modalities involved were selected and (most importantly) integrated together. Indeed, MUVII IKD demonstrated new interaction paradigms and a novel integration of these three interaction modalities: 3D-vision, 3D-audio, and haptic (force, torque, and tactile) feedback.

Innovations of IKD included:

- The multimodality of haptics, 3D-audio and 3D-graphics, to provide an integrated, natural "look and feel" immersion environment for edutainment purposes.

- Design and implementation of a special haptic feedback device that support tactile & 3DOF force feedback, especially designed for educational virtual environments.

- An extensible and modular architecture of the platform that can support the integration of two such haptic feedback devices, thus providing multi-user ability (either teacher-pupil or pupil-pupil) to enhance the teaching procedure and the collaboration among pupils.

- Support for motion capture / tracking for hand and head of two users.

- Sophisticated 3D-sound: use of open headphones, head-tracking and real-time reproduction of individual 3D sound for each user.

- Innovative haptic interaction metaphors, like the combination of visual with haptic or audio with haptic stimuli, aiming at the creation of a multi-sense educational environment.

- Rapid application development support through the integration of a commercial tool (Virtools)

- Innovative Educational Applications: These applications incorporate several innovative features. Their primary purpose is to demonstrate the capabilities of the H3DI, aiming at the rapid adaptation of users in the characteristics (and in the way of use) of the device.

Fig. 3 shows the hardware architecture of the IKD, showing PC hosts in charge of each module and network communication connecting these hosts.

IX.   THE EDUCATIONAL SOFTWARE APPLICATIONS

Haptics means applying tactile (touch) sensation. This feeling can be achieved by using special input/output devices (joysticks, data gloves, or other devices) driven by specially designed computer applications to control these devises. The user can receive feedback from appropriate computer applications in the form of sensations felt in his/her fingers, hands or other parts of his/her body. Tactile feeling can be combined with stereoscopic (3-dimentional) visual display. This combination offers an
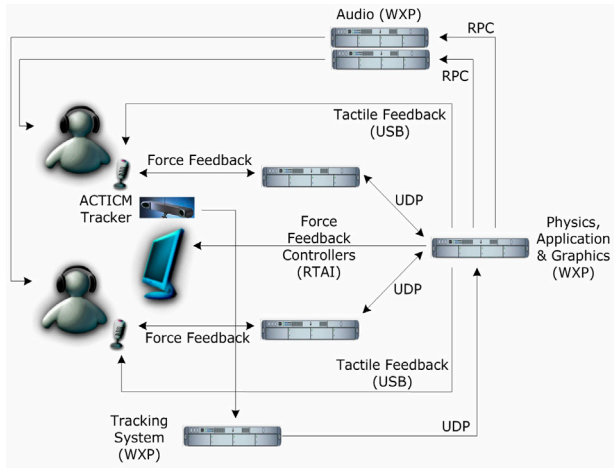
Figure 3. IKD hardware architecture

enormous variety of applications starting from "visual" school laboratories and going as far as learning auto driving, surgery, or even space ship manoeuvres.

In such virtual reality environment, the user can:

- investigate and explore various 3D objects. (Tactile feedback, which involves Material, Surface of objects, Size, Shape, Weight etc.)
- feel force and torque feedback (caused by weight, torque etc)
- select, pick-up, hold, move, orient and release/place objects
- hear sounds that emulate sounds produced by surfaces rubbing against each other or by surface-collision events etc.

Haptics extends the teaching possibilities. In a conventional class environment, when instructing a pupil on the way to achieve a manual task, the teacher will occasionally resort to demonstration through a direct mechanical contact (especially so for younger pupils). Unlike visual demonstration or verbal instruction, mechanical or haptic demonstration is designed to communicate directly to the pupil's hand. Common examples of this kind of teaching occur in sports and music instruction.

With the development of haptic interfaces to virtual and tele-presence environments comes an opportunity to go beyond merely providing environments in which to train users. It should also be possible to demonstrate strategies for manual manipulation, and perhaps even impart a "feel" for a manual task during special training periods. Virtual environments usually provide cheaper and safer platforms for practice (and education) than the real-world settings after which they are modelled. As regards the use of virtual environments in education, the use of haptic feedback can enhance the quality of learning and (perhaps) influence the speed of learning. The present study is a first investigation regarding such claims.

The educational applications that were developed in the framework of MUVII project were built to exploit the advanced features of MUVII IKD platform and device and to investigate their educational potential. Indeed, the

didactical opportunities offered by the system (as it gradually developed) were painstakingly analysed and evaluated. Subsequently, two educational applications were selected for implementation in the IKD: (A) *Newtonian Physics, Trajectories and the Solar System*, and (B) *Virtual Model Assembly – Gears* (each one with learning mode, recapitulation mode and edutainment mode).

From the educational point of view, both educational applications were based on the *constructivist theory* (for an overview of the theory see Ioannidis et al. [7], section 3.5). The basis of the constructivist theory of learning and instruction is formed by the writings of Piaget [10][11] and Vygotsky [15], along with the work of Ausubel [1] and Bruner [3]. According to this theory students are responsible for their own learning, and meaningful learning demands that pupils construct their own knowledge.

Computer aided learning and virtual reality environments allow students to learn by following his/her own pace, or even according to their interest. Using the MUVII IKD educational applications in their "active manipulation" mode, students can manipulate objects after consciously deciding to do so. Thus, users interact with the objects they choose in the way they choose, and feel the feedback from their actions. This stimulates their interest and increases their attention. There are reasons to believe that the knowledge remaining to the student after such a learning activity is higher than what is left after teaching the same subject using traditional methods of teaching, where the student passively hears the teacher teach or watch a science video. The active control on the objects that such software allows (to the user) is recognised as a very important and interesting feature.

Within the application of _Newtonian Physics and the solar system_, the user interactively (and virtually) navigates through the solar system, while collecting information about anything that interests him/her. The user experiences the effect of the forces when accelerating objects (e.g. by trying to throw them off their course) as well as the strength of the gravitational forces applied to objects at different distances from the sun or from a certain planet. Obviously, for the purpose of such an interaction the user is endowed with "super-powers". With the use of haptics the pupils are able to experience, feel and gradually learn the way the laws of simple mechanics in the way these are applied at the scale of our solar system. Fig. 4 shows a screenshot of the application.

Regarding the _Virtual Model Assembly - Gears_, the user is offered a lesson in the history of cogs, gears and their applications through the ages. They can also try to assemble some selected applications by combining gears. The users experience the effect of forces like those caused by weight, friction, motion, rotation etc. This application can also be used to enhance students' understanding of phenomena like the transmission of motion from one part of a machine to another. Fig. 5 and Fig. 6 show two screenshots of this application, the second one using the watermill paradigm.

X. DATA TAKING AND DATA ANALYSIS

According to *constructivism*, teachers only play a supporting role in the learning process. Students' ideas represent the raw material that the students themselves are

Figure 4.   Feeling the gravity
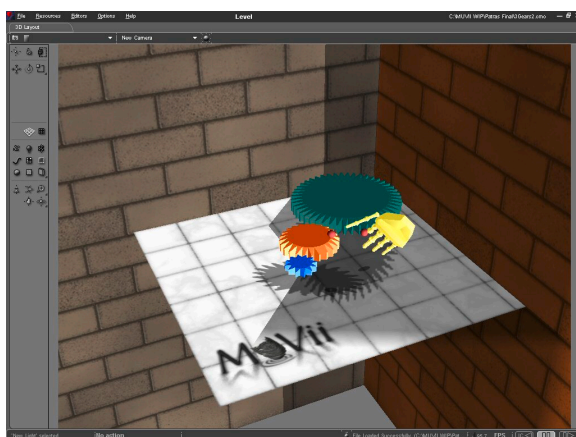(Planet: Mercury. Diameter: 4.878 km)

Figure 5.   Feeling moving gears

called-for to reconstruct. Therefore, the starting point for the teaching procedure was to identify the student's ideas, with a *"pre-test"*.

The trial took place, using students from randomly selected schools. Their teachers were very willing to cooperate, and they pass their positive attitude to their students. It was observed during testing that some children had problems regarding their understanding of written text, and the ability to analyse and evaluate the data presented, with a view to extract various levels of useful information from them.

The students came in small groups of 4 or 5 persons. The procedures started by having the students fill the pre-

test. The students were then introduced to the haptic device one by one, and the rest of the group could observe their classmate who was using the haptic device system.

As the students finished their "haptic experience", another *"post-test"* questionnaire given to them to fill-up. All students had a hands-on experience with the haptic interface, but not all of them followed the same "exercises". The "exercises" for each group of students were chosen according to their age. The curricula for the fields chosen to be taught were designed by professors in collaboration with active teachers, and were implemented by university IT specialists. The research carried out by University instructors and teachers.

It should be stressed here that, due to time limitation (end of the research program), there was no follow-up test to judge the long-term effects of the exposure to the haptic interface and the educational software that was using it. As it stands, the difference in student's response between the pre-test and the post-test shows the student's short-term benefit from this didactical intervention involving haptics. Nevertheless, as most of the questions in the post-test dealt with the students' opinion about the device, the time the post test was conducted is not critical, in the sense that students opinion about the device is not likely to change much with time.

This is, essentially, the essence of the present evaluation: the effectiveness of the educational software and the effectiveness of the haptic interface. Students' change of attitude towards the haptic device before and after the test was also measured and was recorded by the present testing procedure.

Both the IKD and the application software have been tested with schoolchildren that have been randomly selected. It should be mentioned here that mostly due to equipment size, and lack of suitable space in schools, the students that participated in the testing procedure had to visit the device which was set at laboratory at the University of Patras (HPCLab). Members of the Science Laboratory (School of Education) were responsible for the educational trial.

In the present educational trial **163 students** participated:

64 of which were primary school students,

74 were lower secondary school students, and

25 were upper secondary (i.e. lyceum) school students.

Generally, every study (or every measurement, or every evaluation) involves a number of *experimental errors*. Every experimental point measured and finally presented is (in general) only valid within the limits of the experimental errors of the study.

These experimental errors are constituted by the *systematic errors*, and the *statistical errors*, and their values are generally different for each one measurement.

No experimental measurement can avoid *systematic errors*. In any case, in the present study special care was taken so that large systematic errors were avoided. We then went on to evaluate the systematic error remaining, and this was set at **3.5%,** a figure considered to be fair (if not on the low side) and which is consistently comparable with all our statistical errors. This means that we believe our total error to be neither statistics-dominated nor systematics-dominated, and this holds for every single data-point presented.

All relevant statistics were calculated using specially constructed software, interfaced with a popular computational and plotting package. The **statistical variance** was computed and the **Bessel-corrected standard deviation** was calculated for all data points to be presented. The **total experimental error** was then found by adding in quadrature our systematic with our statistical errors (these two being independent, by definition), and receiving the square root of this sum.

Bar diagrams are not suitable to describe the results of experimental research, while they are suitable for comparison of elements when the measurement is beyond argument or with minimal margins for errors (e.g. number of ships that belongs to various companies in a certain day). The same is true for numerical percentages that are simply presented without the quantification of the experimental errors.

Therefore, the data in this study are presented in histograms, depicting the *percentage* of students holding a particular idea. The error bars on each point of the histogram depict (numerically) to one total standard deviation on either side of the point, as calculated for this specific point. In *some* of the questions presented, the students could choose more than one answer. For this reason, it is possible the sum of the percentages to add-up to something above 100. *Green squares* stand for the primary school sample, *red triangles* stand for the lower secondary schools, while *blue circles* stand for the upper secondary schools.

XI. PRE-TEST: QUESTIONS POSED TO THE STUDENTS BEFORE THEY WERE EXPOSED TO THE MUVII SYSTEM

A. Pre-test question 1.a: Have you used computers at home?
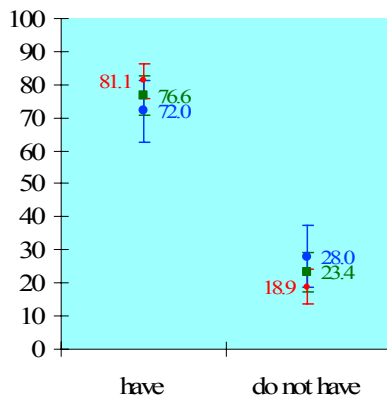
Green squares stand for the *primary school sample*
Red triangles stand for the *lower secondary schools*
Blue circles stand for the *upper secondary schools*

It would seem that most parents buy a computer to their children quite early.

B. Pre-test question 1.b: If you answered yes to the previous question then what type of activities have you performed with the computer? (You may select more than one answer, if you like).
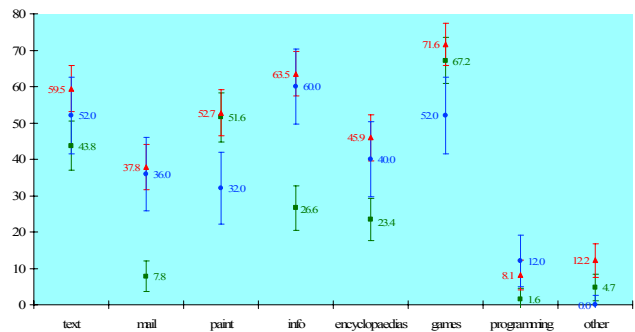

Most children (of all ages) use their home computer in order to write texts, play games and even to paint. Older children use their home computer for internet-based activities (info search, and some e-mailing, and chat). The use of computer or web-based encyclopaedias is increasing in the secondary school (from 23% ± 5,9 to about 40% ±10,3 – or even more in the lower secondary schools) while applications like paint tend not to be used as children grow older. Not many children have used the home-PC for programming (only 12% ± 7,1) for the upper secondary school. The use of e-mail is still relatively rare in Greece. Generally the penetration of the internet in Greek homes is still low, the second lowest in the "old" i.e. 15-member E.U.

*C. Pre-test question 2.a: Do you have a computer at school?*
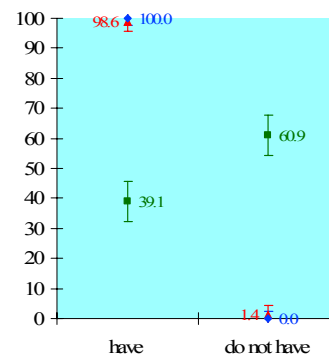
There is a significant difference between the younger (primary school) and older children (secondary school) as almost all of the later have a computer at school. We should mention here that according to normal school curriculum ICT is a lesson only for secondary schools (lower and upper). For primary schools, the situation is less clear-cut. For some schools (those with all-day classes) technology is taught in the afternoon as a part of the extended curriculum. Alternatively, the parents' association often hire a teacher to give computer lessons to their children.

D. Pre-test question 2.b: If you answered yes to the previous question then what type of activities have you performed with the computer? (You may select more than one answer, if you like)
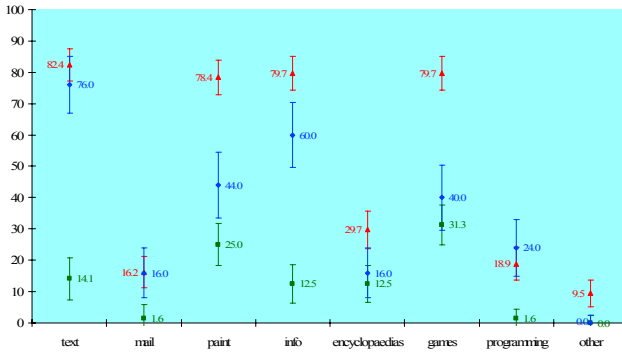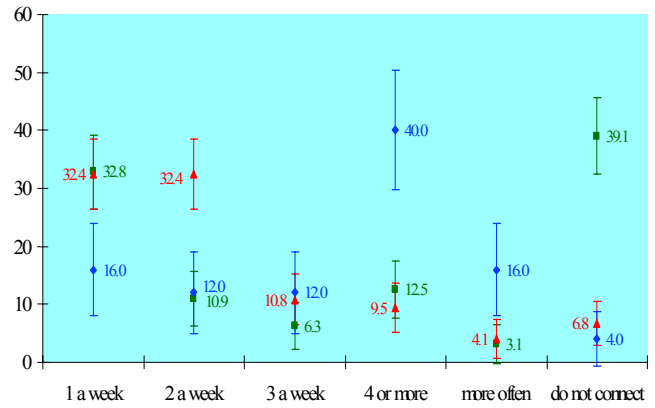

Most secondary school children use the school computer in order to write text. The use of e-mail is still relatively rare in Greece, especially school email. Older children use computer for info search on the web (especially the lower secondary schools). It is worth mentioning here the high percentage of the students that play games while attending ICT lessons at the school lab! These percentages range from 31,3% (± 6,4) for primary school children to almost 80% (±5,3) for the lower secondary school. The use of computer or web-based encyclopaedias is still rare at schools (most likely because the best of them are not available in Greek). Not many children have used the PC for programming (i.e. only 24% ± 9,0 of upper secondary school). Applications like paint tend to be used especially from the apparently very computer-active lower secondary. Indeed the upper secondary is less computer-active overall, than the lower secondary.

E. Pre-test question 3: From where do you connect to the Internet
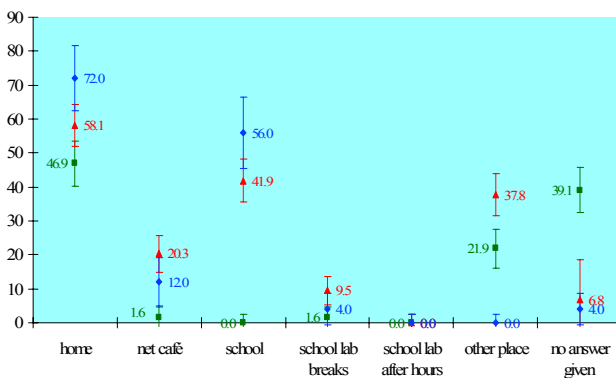
Primary schools are far behind the times as regards internet connection. Most primary school students connect to the net from home. The situation is better at secondary schools and lyceums. Most students connect to the internet from home, but school lab holds a good percentage. Greek students do not favour internet cafes and therefore internet cafes do not have high percentages. If we combine the above answers with the ones in the previous question (referring to PC use at school), we deduce that children do use internet, but mainly for surfing.

F. Pre-test question 4: How often do you connect to the internet?

It can be observed that the older the students are, the more often they seem to connect to the internet, something which was expected, while primary school children mostly seem to connect once a week, lower secondary students are equally balanced connecting once or twice a week, while some students connect more often. The high likelihood rate for upper secondary school students is four times a week.

G. Pre-test question 5: What do you usually do while you are on-line (You may select more than one answer, if you like)
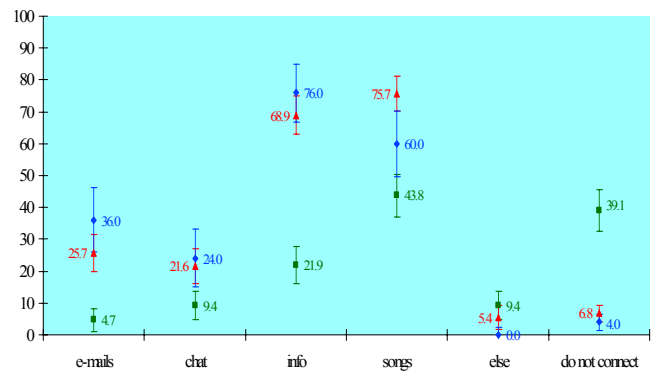

Students use the net to search for songs; the older use it also for chat. Upper secondary school students use also internet in order to find information that might (perhaps) also be related to their studies.

H. Pre-test question 6: Which of the following items are absolutely necessary for the operation of a Personal Computer?

This question was intended to judge students' understanding of ICT. This is meant not in terms of using ICT, but in terms of how computers operate.

The results are interesting but not very surprising. Primary school children identify as necessary components these they can see (the operating system is a CD for them) but they fail to identify the power supply, which is absolutely necessary. Older students understand ICT operation better.
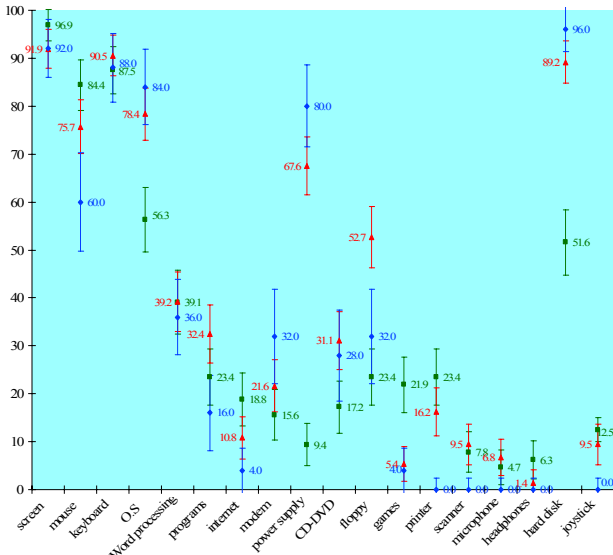
We can deduce that the school education system is (basically) on the right track for achieving some understanding of PC operation amongst pupils. Whether the present trial could be judged as satisfactory or not is open to interpretation. We could always do better.

I. Pre-test question 7: Which of the following items are not necessary for the operation of a Personal Computer?
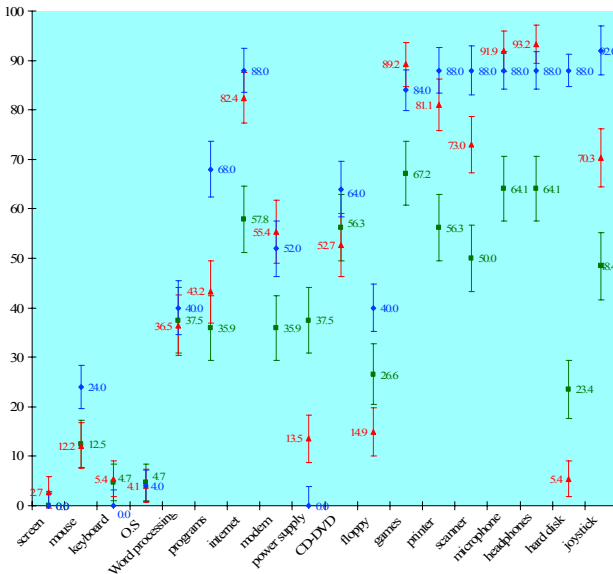
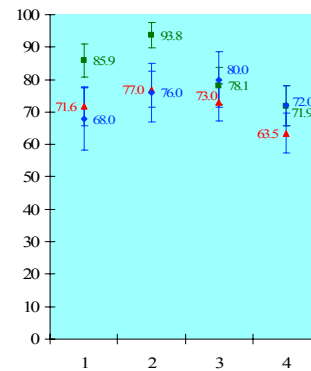Older students give more consistent results. In general, all the remarks made on the previous question (6) apply here as well.

J. Pre-test question 8: Would you like to attend special computer lessons explaining (in detail) how computers work?
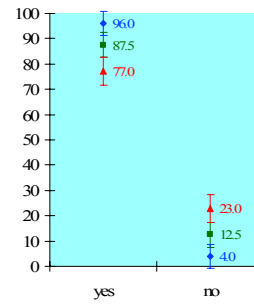
We note a high level of interest about ICT and its operation from most students, even the upper secondary school students that have already followed ICT lessons would be willing to participate in an in-depth lesson about computers and how they work.

K. Pre-test question 9: These are the shapes of some planets and their corresponding mass. Which planet do you think that has the stronger gravity? Match each planet with his gravity

Γη	**Δίας**	**Κρόνος**	**Ποσειδώνας**
Μάζα: 5,98x10²⁴ Kgr	Μάζα: 1,89x10²⁷ Kgr	Μάζα: 5,69x10²⁶ Kgr	Μάζα: 1,03x10²⁶ Kgr

1. Earth	**2. Jupiter**	**3. Saturn**	**4. Neptune**
Mass 5.98 x 10^{24} Kgr	Mass 1.89 x 10^{27} Kgr	Mass 5.69 x 10^{26} Kgr	Mass 1.03 x 10^{26} Kgr

Most students responded well, but a sizable proportion seems confused. We believe that the concept of mass, volume and gravitational force are mixed - up in the minds of some students. It is interesting to note that during the pre-test, older students did not come with better ideas as to what gravity is and how it works (e.g. operates). This is as clear a failure of the educational system as it can ever be!

L.   Pre-test question 10: In the following picture gear A rotates clockwise at a stable speed (you can see the arrow on the figure indicating the direction of the rotation). Please draw similar arrows on the picture indicating the direction of rotation for the gears B and C (or Γ as in the picture, below).
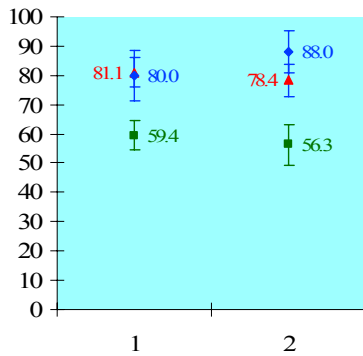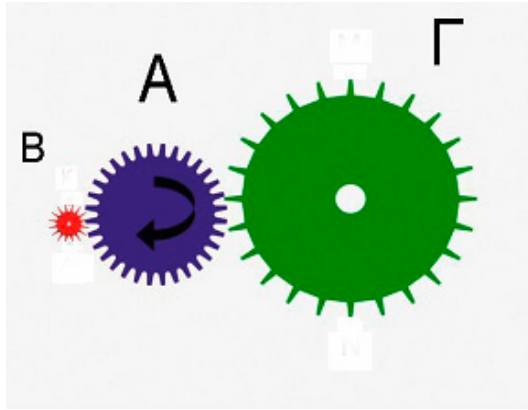
Most students during the pre-test questions responded quite well with their "prediction" on what will happen. Older students did (normally) better.


XII.   QUESTIONS POSTED TO THE STUDENTS AFTER THEY WERE EXPOSED TO THE MUVII KIOSK (POST-TEST)

A. Post-test question 1: What do you think about using the haptic device in everyday classroom teaching and learning processes?

1. *Interesting*
2. *Something different*
3. *Boring*
4. *I couldn't understand what it was doing*
5. *If you liked it, please briefly explain the reason why*
6. *No answer given*

The percentage of older children found teaching with the use of a haptic device interesting is quite large. Quite a few from the younger children on the other hand preferred not to answer this question. Suggesting that they were not used to give overall personal opinions lower secondary school students were more willing to give an explanation as to why they liked it. We should also mention here that 0% (± 3,5%) of the students found the procedure boring or not interesting, while for the lower secondary schools the

percentage was 1,4% (± 3,7%). Although all students seem to be positive to their experience, very few offered an explanation why they liked it.
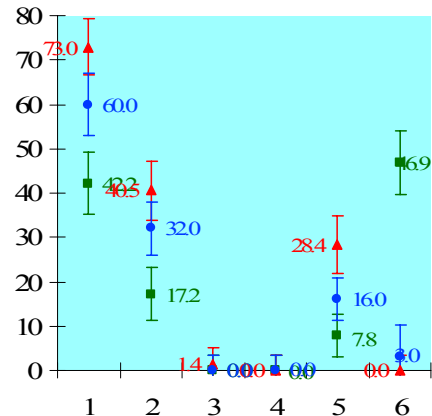

B. Post-test question 2: How did you find the content of the teaching procedure?

1. *Interesting and relevant to school curriculum*
2. *Interesting but not relevant to school curriculum*
3. *Boring*
4. *Too difficult for me*
5. *No answer given*
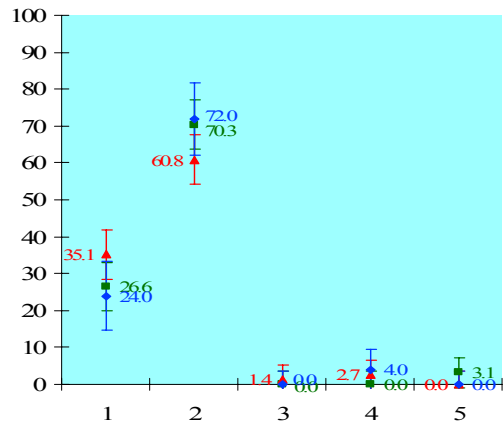
Most of the students found the new "curriculum" interesting but not relevant to the school curriculum. School curriculum is old fashioned and only in very few occasions we can find examples contained in the curriculum that can also be implemented for a haptic interface. By judging "the content not related to the school curriculum", the students simply verify the widespread opinion amongst Greek educationalists (as well as other European educationalists) that curriculum is text-based and not knowledge-based, and students are asked to memorize text and are examined on that, as opposed to their understanding the procedures. In a way, this is a large complement to the content, which has been selected to the MUVII. Being "non relevant" to school curriculum really means important and deeper than curriculum-depth. No student found the experiment boring or too difficult (which is another compliment).

C. Post-test question 3: Referring to the planet's scenario: compare the gravity you felt in Earth, with the gravity you felt in "Jupiter", "Saturn" and "Neptune"

Jupiter

Saturn

Neptune
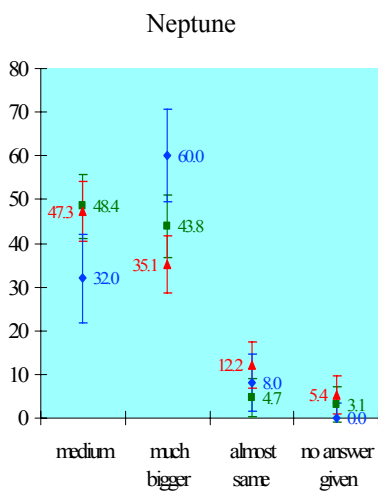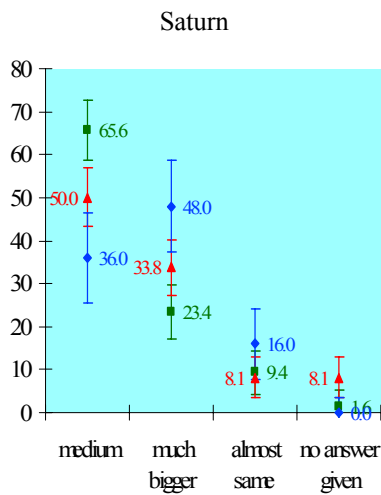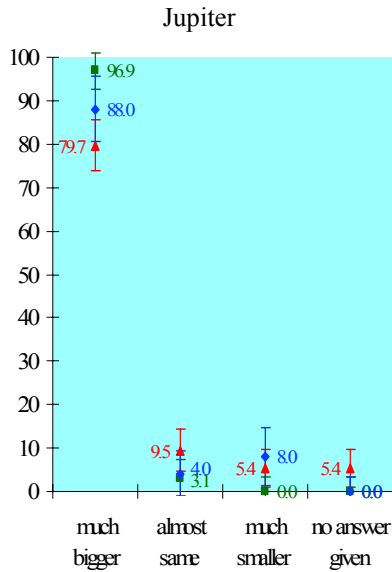
Judging the answers to this question overall we observe that children responded quite well. Most students chose the correct answer most of the time. If we compare these answers with these of the pre-test, we find an overall increase in understanding. This really is **"understanding by feeling"**!

D. Post-test question 4: At the gears teaching procedure, you tried to stop the gears using your finger. Did you use the same or different force on each one?
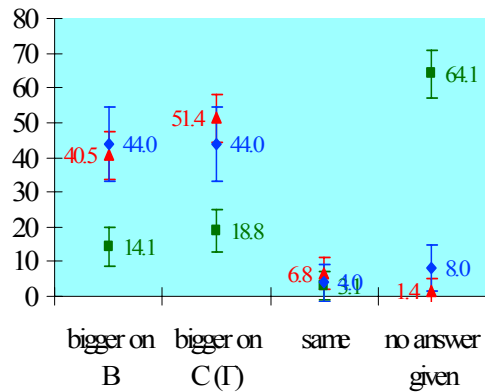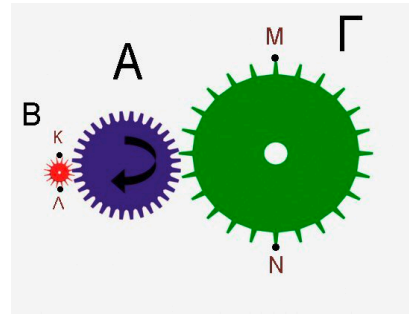
The biggest percentage of the Primary school children did not answer this question. The secondary school children seem to be evenly split in this answer. Half of them choose the big gear and the other half the small one. Both lower and upper secondary school children seem to be evenly split on what is correct answer (which was expected for them). There seemed to be a generally held idea that one of the forces should be lower than the other one (e.g. not equal, that is). If more time was given to this exercise, perhaps the results were better.

E. Post-test question 5: While you were trying to stop the gears B and C with your two fingers by pushing first at the points K-L and then at the points M-N (like the picture), did you feel the same force on your fingers?

The biggest percentage of the Primary school children did not attempt to answer this question. The lower secondary school children, on the other hand, seem to be confused. Half of them chose the big gear and the other half the small one, while only the upper school students responded quite well. This might indicate that greater observational ability is needed (which comes with higher age) in order to comprehend this question fully.
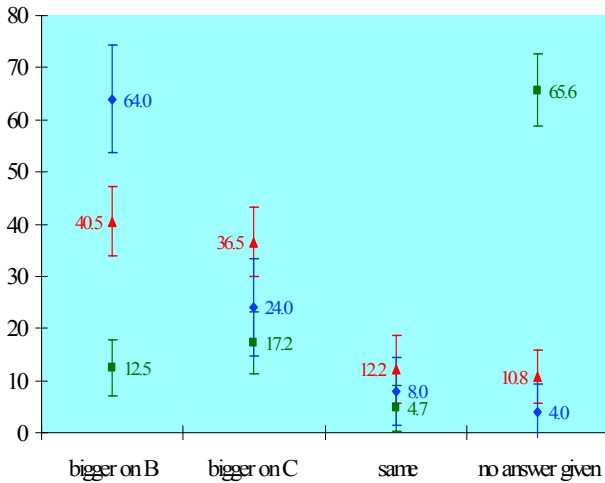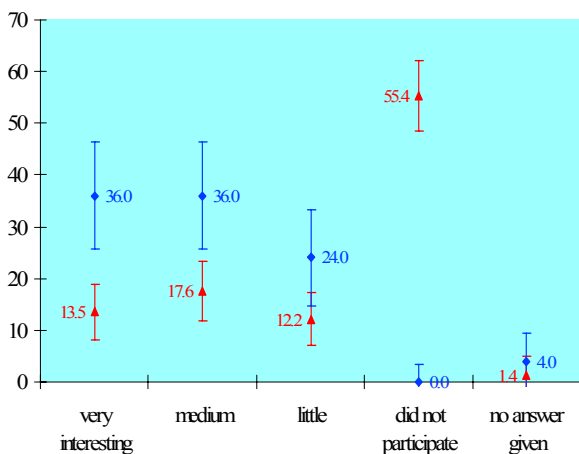
F. Post-test question 6a: Answer freely according to your opinion how interesting did you find the applications.

Planets
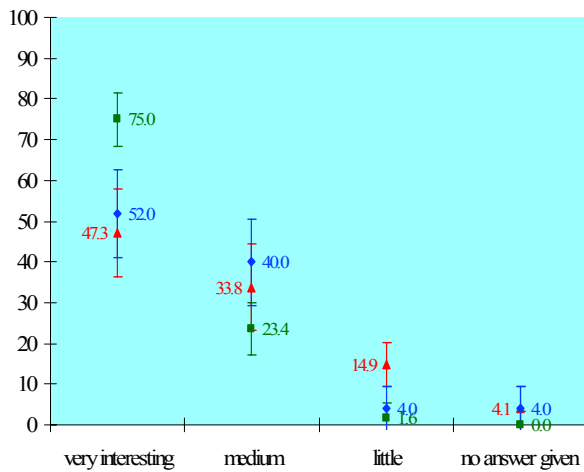
The great majority of students were interested one way or another. Younger children by being naturally "enthusiastic" found the curriculum interesting in higher percentages than the older ones.

Watermills

The primary schools did not take this exercise. It could be seen that only upper secondary school children found this application interesting. This is not surprising as this application was characterized by the researchers as a difficult one. Almost half of the lower secondary school students did not worked with this application. This is due to the difficulty of the application, and also due to time limitations.

Gears
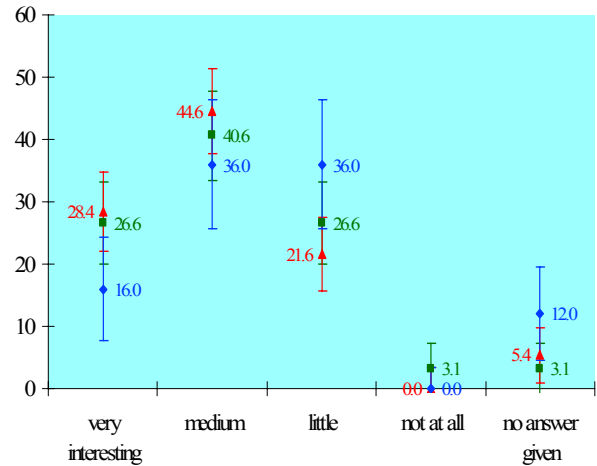
Most children choose the "medium" selection, when responded on how interesting they found this application.

G. Post-test question 6b: Grade the applications according to your personal opinion, by taking into account how understandable they were.
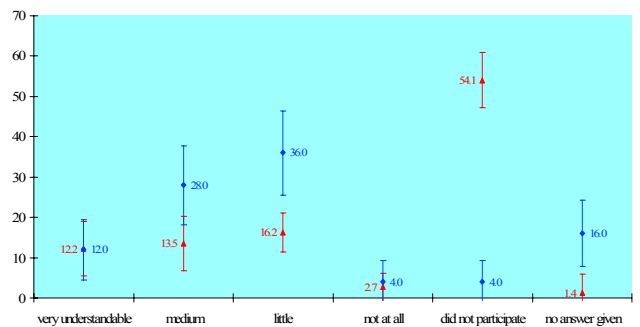
Planets

Primary school children found this application understandable, while the percentage of older students holding the same opinion falls to less than 50%.
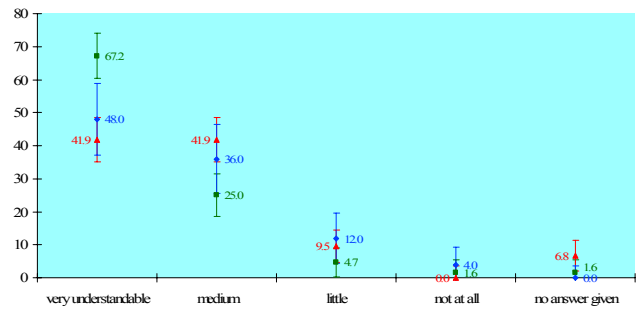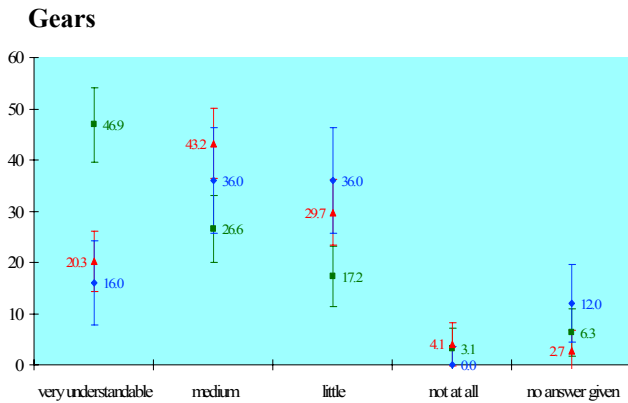

Watermills

The primary schools did not take this exercise, but the results from the secondary schools are presented here.

It can be observed that most children found this application not very interesting. Primary school children were not tested to this application, because this application was not meant for their age group.

Gears

Primary school children were more enthusiastic with this application.

H. *Post-test question 7: New technology helps us to carry out some experiments which are very difficult or impossible to be done in the normal classroom. Do you agree?*
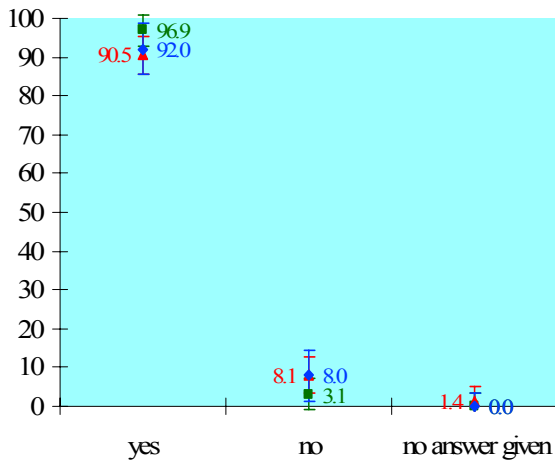
At least all students seem to agree that ICT is useful for performing virtual experiments.

I. *Post-test question 8: Did you have any problems/difficulties with the equipment or the programs you have just used?*
   1. *I did not face any difficulties. All worked perfectly.*
   2. *I had some difficulties with the device*
   3. *There were some technical problems concerning the device.*
   4. *The applications were too difficult and complicated.*
   5. *The application did not work as expected.*
   6. *no answer given*
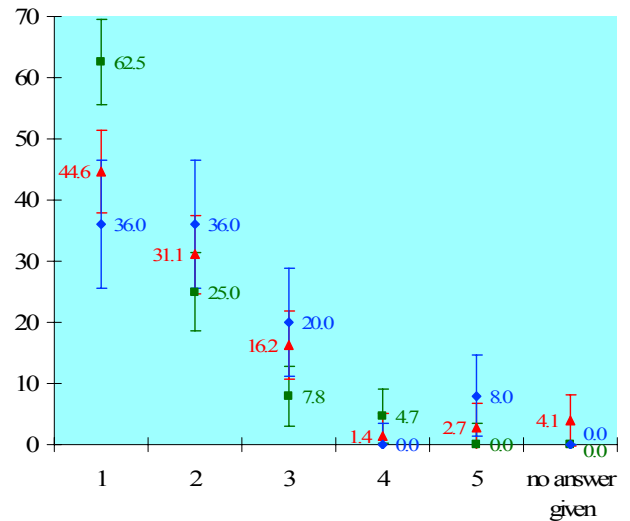
Although we detect that older students appear to be more critical of the shortcomings of the setup, most students seem to have found no difficulties.

J. *Post-test question 9: Would you like to participate in another lesson using a device similar to this one?*
   1. *Yes I will certainly participate if offered at school*
   2. *Yes, I will certainly participate and I wish I could have access to these media from home*
   3. *I am not sure*
   4. *Definitely not! – I would not like to participate to another one*
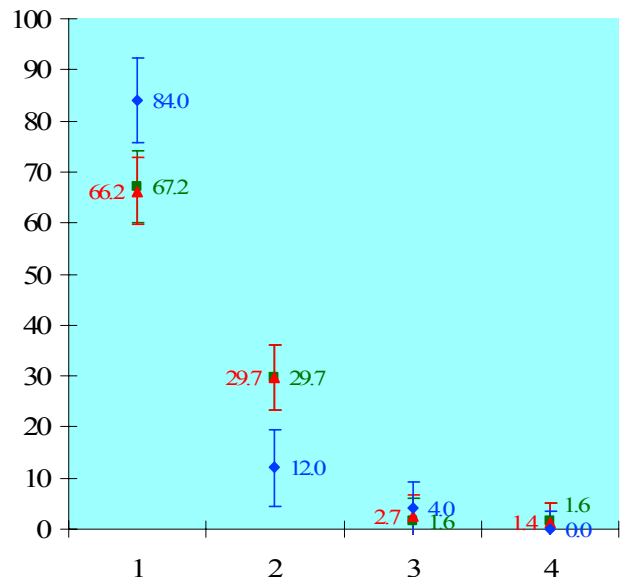
The majority of the students 67.2% (± 7,0%) for the primary school students, 66.2% (± 6,6%) for the lower secondary school students and 84% (± 8,3%) of the upper secondary school students, are willing to participate in another lesson with the use of a haptic interface, while a percentage of them would also wish to have had such a device available for home use. This, we believe, has to do with the size of the device (i.e. students realised the space limitations at their homes).

XIII. EVALUATION OF TACTILE FEEDBACK

The IKD applications integrated tactile feedback to provide two types of feedback. The first is feedback to the user's fingertips when the avatar collides with a 3D object (rapid movement of tactile motor). The second is to provide information to user's hand for the kind of material the user holds in his hand (a constant movement of tactile motor with different pattern for different material). Due to limitations in development time, it was impractical to exploit fully the advances of tactile feedback in every application. The different types of material simulated included wood, iron etc, while the tactile feedback of collisions was integrated and tested in the "gears" application.

The students tested these two applications with and without tactile feedback. They were very enthusiastic and happy about this strange feeling on their fingertips. They enjoyed more the applications when the tactile feedback was present. However, as tactile motors provide a "metaphor" of feeling rather than a realistic one, students asked for an enhancement of the feel, in order to provide a more realistic sensing.

The conclusion is that tactile motors can be used only as metaphor (in fact it was designed for this purpose). The user should be allowed for a short training on the tactile patterns before using the real applications, so as to appreciate the "messages" of the tactile feedback and learn how to perceive it. This kind of feedback, which is very innovative in haptic devices, enhances a lot devices such as the IKD as well as educational software like the applications presented.

XIV. DISCUSSION AND CONCLUSIONS

Students responded quite well to the use of this haptic prototype, although this could be made to look "friendlier". Students were also pleased and seemed to be even amused by their experience. They would like to repeat the experience they have had and they would also like to see the haptic device extend its abilities; in addition they wanted to see haptics and the whole IKD device in particular being used in other (more varied) applications.

The test period of the MUVII applications lasted more than three months, and therefore we had the opportunity to let a considerable number of students test the device (although an even longer testing time would have allowed us to test it with an even greater number). Naturally, some technical problems have also been experienced; these had to do with the fact that IKD was used for many hours per day (more than 6 hours). These problems caused no significant handicap to the testing procedure. Some small delays were inevitable, but students understood that this was expected, as with any innovative technology. It is with the greatest of pleasures that can be reported that not even one person left the kiosk without trying out the haptic device due to technical problems.

The encouraging result from this investigation is that we can easily use IT to teach science (and perhaps other subjects) even with primary school students. Pupils seem to *respond quite well* in using the screen as well as the haptic device and they faced no difficulties with the MUVII kiosk, overall. Today children are used to playing "game boys", mobile phone games, and other such electronics and, therefore, they easily adapt to the computer manipulation of devices such as the MUVII

haptic interface. This seems to be true even for children with small previous computer experience.

The students of the primary schools had many clerical questions relating to the pre-test and the post-test, as they were unfamiliar with tests in general. Naturally, they received help in improving their technique in answering questionnaires. It was observed in many occasions that they were trying to talk to each other, in an attempt to find answers to those questions they found difficult to answer. For the lower secondary school students it was easier to answer the pre-test questions, while the upper secondary school students found it much easier overall.

- A large proportion of children found teaching with the use of a haptic device interesting.
- Most of the students found the new "curriculum" interesting but not relevant to the school curriculum.
- No student found the experiment boring or too difficult (which is a big compliment!), but see also the comment below.
- Assessing the learning achieved using the application on the Newton's law on gravity, we observe most students choosing the correct answer most of the time. By comparing these answers with these of the pre-test, an overall increase in understanding is obvious. This really is **"understanding by feeling"!**
- On the question about the force felt by gears of different size, the results were mixed, these being better for secondary school students. This might indicate that greater observational ability is needed (which comes with higher age) in order to comprehend this question fully.
- The great majority of students were interested in the haptic application (as well as the device) one way or another. Younger children by being naturally "enthusiastic" found the curriculum interesting in higher percentages than the older ones.
- The majority of the students were willing to participate in future lessons using devices with haptic interfaces, while a sizable proportion of them would also wished to have had such a device available for their personal use at home.

All students seemed excited and very happy after the testing. They asked details like the cost of the haptic device, who constructed the machine, if game-applications will become available in the future etc. It was also observed that generally the girls seemed to consider (e.g. to think about) their hand-movements before they made them, and as a result, their handling of the haptic device was steadier. The boys seemed to be more impulsive (-anxious even) and made quick movements (almost jerky, sometimes). The above are general observations made by the researchers for the bulk of the students, while it should be stressed that individual handling skill differed amongst students.

Most students commented that it would have been more interesting if they could have haptic feedback in all five fingers. Students also claimed that it would have been better if more applications were available (e.g. additional educational software or games). Students also reported

that the fit of the haptic interface needed improvement to become more adjustable to their size.

We should mention here that two primary school children were very afraid on the sight of the haptic device, (they cried and denied to use it at first, although they later changed their mind and asked to try it after watching their classmates in action). This is a simple question of appearance (looks). The haptic device can be made to look more attractive and "softer" (i.e. hide its metallic character). This is a cosmetic change and can be implemented.

Written as well as oral interviews were also taken from the teachers of the students which participated in the present research and they all were very happy with the experience (both their own and their students).

Conclusions: Despite the fact that (macroscopically) the present research can only be considered as preliminary, it would seem to indicate, nevertheless, that the introduction of IT-related assistance in teaching presents the best opportunity for attempting a major reform in teaching approaches, today. This momentous opportunity should not to be missed, as it would benefit Europe and all humanity. Therefore, much more research is needed on teaching approaches that involve the use of IT.

Coming to the subject of advanced haptics (offering force, torque, and tactile feedback), more research is also needed on the subject of advanced haptic interfaces as well as more research is needed on the development of haptic-based applications that are educationally useful and didactically correct. The present results are very encouraging. MUVII represents the first serious attempt to do such (didactically driven) development using an advanced haptic interface, and as such (reflecting to the whole "MUVII team") we feel that the results were indeed quite a success.

REFERENCES

[1] Ausubel, D. (1968). Educational psychology: A cognitive view. New York: Holt, Rinehart & Winston.

[2] Bird M. and Gill G. (1987) Individual differences and technology attributes: An examination of educational technology considerations related to trade and industry training, Australian Journal of Educational Technology, 3, 2, pp. 108-118

[3] Bruner, J. (1990). Acts of meaning. Cambridge, MA: Harvard University Press

[4] Hayward V., Astley O.R., Cruz-Hernandez M., Grant D. and Robles-de-la-Torre G. (2004) Haptic interfaces and devices. Sensor Review 24(1), Emerald Group Publishing Ltd., ISSN 0260-2288, pp. 16-29

[5] Ioannidis G.S. and Garyfallidou D.M. (2001) Education using information and communication technology (ICT), and ICT education: categories methods and trends, In: Auer M. and Auer U. (Eds.) Proc. ICL2001 workshop: "Interactive Computer aided Learning, Experiences and visions", Villach, Austria, Kassel University Press, ISBN 3-933146-67-4

[6] Ioannidis G.S. and Garyfallidou D.M. (2004) A novel educational software to teach energy in its entirety was designed, developed, and tested: the first educational results, ICL International Conference Villach Austria 2004, ISBN 3-89958-089-3.

[7] Ioannidis G.S., Garyfallidou D.M., and Spiliotopoulou-Papantoniou V. (2005) Streaming Media in Education, and their impact in teaching and learning Educational best practices and some first observations of their implementation. Published by Education Highway, ISBN 3 – 9500247 – 4 – 3, (First Edition, July 2005), also available at http://estream.schule.at/

[8] Itan, Y. (2005) Human motion perception mechanisms: A functional magnetic resonance imaging experiment applying Computational, Psychophysical and Physical methods, available at: http://www.homepages.ucl.ac.uk/~ucbpyit/Essay3PDF.pdf (visited in February 2008).

[9] Okamura A.M., Richard C. and Cutkosky M.R. (2002) Feeling is believing: Using a force-feedback joystick to teach dynamic systems, ASEE Journal of Engineering Education, 92, 3 (Jul 2002), pp. 345-349

[10] Piaget, J. (1972). The psychology of the child. New York: Basic Books.

[11] Piaget, J., Gruber, H. (Ed.), & Voneche, J. J. (Ed.) (1995). The essential Piaget Publisher: Jason Aronson; 100th Anniversary Ed

[12] Sathian, K., Zangaladze, A., Hoffman, J. M. and Grafton, S.T. (1997) Feeling with the mind's eye, NeuroReport, 8, (1997), pp. 3877–3881

[13] Solomon, J. (1993) Teaching Science, Technology and Society, Open University Press (1993) p.17.

[14] Stefani A., Vassiliadis B., Xenos M., "On the Quality Assessment of Advanced e-Learning Services", International Journal of Interactive Technology and Smart Education, Vol. 3, Issue 3, pp. 237-250, August, 2006.

[15] Vygotsky, L.S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.

[16] MUVII Web Site (WWW), IST Project: Multi User Virtual Interactive Interface, http://muvii.hpclab.ceid.upatras.gr , visited in February 2008

[17] Nano-Scale Science Education research group (WWW), College of education, NC State University, http://ced.ncsu.edu/nanoscale/haptics.htm visited in February 2008

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