Ανοικτή Εκπαίδευση: το περιοδικό για την Ανοικτή και εξ Αποστάσεως Εκπαίδευση και την Εκπαιδευτική Τεχνολογία

Τόμ. 5, Αρ. 1 (2009)

Τι είδους συσκευές απτικής ανάδρασης και εφαρμογές χρειαζόμαστε στην εκπαίδευση; Οι απαιτήσεις, οι προδιαγραφές και η εμπειρία που αποκομίσθηκε από ένα IST πρόγραμμα

S.P. Christodoulou, D.M. Garyfallidou, G.S. Ioannidis, T.S. Papatheodorou, E.A. Stathi

doi: [10.12681/jode.9695](https://doi.org/10.12681/jode.9695)

Open Education - The Journal for Open and Distance Education and Educational Technology
Volume 5, Number 1, 2009 © Open Education ISSN: 1791-9312

What kind of Haptic devices and applications are needed in education? Requirements, Specifications and hands-on experience derived from an IST project

Τι είδους συσκευές απτικής ανάδρασης και εφαρμογές χρειαζόμαστε στην εκπαίδευση; Οι απαιτήσεις, οι προδιαγραφές και η εμπειρία που αποκομίσθηκε από ένα IST πρόγραμμα

S.P. Christodoulou[1], D.M. Garyfallidou[2], G.S. Ioannidis[2], T.S. Papatheodorou[1], E.A. Stathi[1]
e-mail: spc@hpclab.ceid.upatras.gr, D.M.Garyfallidou@upatras.gr, gsioanni@upatras.gr, tsp@hpclab.ceid.upatras.gr, stathie@hpclab.ceid.upatras.gr

[1] HPCLab, Computer Engineering & Informatics Department,
[2] The Science Laboratory, School of Education,
University of Patras, 26500 Rion, Patras, Greece

Abstract
In this paper the question whether Haptics technology (virtually touching objects and feeling forces), could be effectively implemented in the teaching procedure is studied, as well as if this technology can be used in improving the understanding of certain scientific concepts. Under the framework of an IST European program called MUVII, a new haptic device was designed especially for educational purposes and a prototype was implemented. This device was designed after thorough consideration of the educational needs. During this process, the most important parameters of the end user requirements were drawn up, and the functionality of the end product was discussed with a team of educational experts (the team also included teachers). These requirements were converted into specifications for a large scale system, called the Interactive Kiosk Demonstrator (IKD). IKD's objective 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. For the application software design (focusing especially on the context of science education) the educational needs of the end users were thoroughly analyzed and evaluated and, subsequently, some applications were designed and developed. These applications have been used and tested by students of different ages, and their teachers, for a period of over three months in order to divulge the benefits and the drawbacks of the haptic device as well as the applications. Some remarkable results were derived from the users' feedback, which support the view that haptic interfaces can be significantly beneficial to the students' education.

Keywords: Haptic Devices, Science Educational Applications, Specifications, User requirements, Virtual Reality.

Περίληψη
Η παρούσα εργασία μελετά το ερώτημα εάν η τεχνολογία των Haptics (συσκευές απτικής ανάδρασης που επιτρέπουν στον χρήστη εικονικά να αγγίζει αντικείμενα και να αισθάνεται δυνάμεις) θα μπορούσε να ενσωματωθεί αποτελεσματικά στη διαδικασία διδασκαλίας στα σχολεία, καθώς επίσης και εάν αυτή η τεχνολογία θα μπορούσε να χρησιμοποιηθεί για να βελτιώσει την κατανόηση ορισμένων επιστημονικών εννοιών. Στα πλαίσια ενός IST ευρωπαϊκού προγράμματος με το ακρωνύμιο MUVII, μια νέα Haptic συσκευή σχεδιάστηκε ειδικά για εκπαιδευτικούς σκοπούς και κατασκευάσθηκε ένα πρωτότυπό της. Η συσκευή αυτή σχεδιάστηκε μετά από τη λεπτομερή μελέτη και εκτίμηση των εκπαιδευτικών αναγκών. Κατά τη διάρκεια αυτής της διαδικασίας, οι σημαντικότερες παράμετροι των απαιτήσεων των χρηστών καταγράφηκαν, και η λειτουργικότητα του τελικού προϊόντος συζητήθηκε με μια

ομάδα εκπαιδευτικών εμπειρογνωμόνων, η οποία περιελάμβανε και δασκάλους. Αυτές οι απαιτήσεις μετασχηματίστηκαν σε προδιαγραφές για ένα σύστημα μεγάλης κλίμακας, αποκαλούμενο Interactive Kiosk Demonstrator (IKD), δηλαδή το «κιόσκι» επίδειξης. Ο στόχος του IKD ήταν να επιδειχθούν καινοτόμοι τρόποι αλληλεπίδρασης ανθρώπου-μηχανής, σε ένα ολοκληρωμένο περιβάλλον εικονικής πραγματικότητας που θα περιλάμβανε, τρισδιάστατη εικόνα, καινοτόμο τρισδιάστατο ψηφιακό ήχο και απτική ανάδραση (αίσθηση δυνάμεων, ροπών και αφής). Για το περιβάλλον του IKD σχεδιάστηκαν και υλοποιήθηκαν νέες εξειδικευμένες εκπαιδευτικές εφαρμογές, που εστιάζουν ειδικά στην εκπαίδευση θετικών επιστημών. Για τον σχεδιασμό αυτών των εφαρμογών οι εκπαιδευτικές ανάγκες των χρηστών αναλύθηκαν λεπτομερώς και αξιολογήθηκαν. Οι εφαρμογές αυτές χρησιμοποιήθηκαν και δοκιμάστηκαν από μαθητές διαφορετικών ηλικιών και τους δασκάλους τους, για μια περίοδο μεγαλύτερη των τριών μηνών, προκειμένου να διαπιστωθούν τα οφέλη και τα μειονεκτήματα της Haptic συσκευής καθώς επίσης και των εκπαιδευτικών εφαρμογών. Μερικά αξιοσημείωτα αποτελέσματα προήλθαν από τους ίδιους τους χρήστες (με την συμπλήρωση ειδικών ερωτηματολογίων), τα οποία υποστηρίζουν την άποψη ότι οι Haptic συσκευές μπορούν να είναι σημαντικά επωφελείς στην εκπαίδευση των μαθητών σε όλες τις βαθμίδες.

Introduction to Haptics, 3D Graphics and 3D Sound

Initially, it is useful to define some terms of *Haptics*, *3D Graphics* and *3D Sound*, since most haptic devices use this kind of technology.

The term *haptics* was popularized in the United States by the philosopher Gilles Deleuze and comes from the Greek verb "haptesthai", which means to touch and to handle. The technology refers to the ability of touching and handling virtual objects. In a more general sense, it is an interface that enables users to understand the weight, the shape, the volume of an object and the forces acting on it. By using *special input/output devices* (joysticks, data gloves, or other devices), users can receive feedback from computer applications in the form of sensations felt on the fingers, the hand, or other parts of the body. The term *"tactile feedback"* refers only to the sensory input on the fingertips of the user.

With *3D (three-dimensional) graphics* we refer to a space where objects (polygons) are made up by a series of dots which are referred to as corners. The coordinates of these corners are specified by three values: x, y and z. The representation of the 3D space on each of user's eyes is always a 2D image obtained through the rendering process. The impression of 3D is created in the human mind after some (quite elaborate) computation, albeit without conscious effort from the part of the user. Many parameters are used as input to this computation, like the different 2D image in each eye, different colouring (hue) of objects as distance increases, common assumptions as to the size and speed of various objects etc.

As far as *3D sound* is concerned, true 3D sound has genuine depth and width to it. Just like 3D graphics, 3D sound can also be recreated by just two speakers and some very advanced mathematics! The use of 3D graphics and 3D sound combined with haptic feedback create a multi-sensory immersion for the users.

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 objective of MUVII project (WWW) was to develop on the one hand two new Man-Machine-Interface Devices featuring haptic feedback, called Haptic-3D-Interface (H3DI), and on the other hand a prototype of an innovative integrated platform using the device: the Interactive Kiosk Demonstrator (IKD). 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).

Nowadays, educational content and applications are developed everywhere. The use of web-based applications to institutions and universities of higher education has been extensively used, especially on distance education universities, like Hellenic Open University (Papadakis et. al., 2005). However, when talking about teaching in primary and secondary schools the opportunity of having a natural "look and feel" environment for teaching purposes is very promising 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 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 the present paper the first two steps of this process are described, and some conclusions regarding the issues raised in them are drawn, which can be used as a useful guide for those interested in developing haptic interfaces and applications for educational purposes.

User Requirements Gathering

In order to collect the most important user requirements, several discussions with potential users (mostly with teachers and to a lesser extent with students) were held. It is interesting to note that although students normally have a better knowledge of computers than their teachers, they are also "dreamers" and ask for features that are not feasible yet.

During these discussions the concepts behind the current haptic technologies (force and tactile feedback) as well as our ideas were explained. 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 a setup involving commercial haptic interface devices (like Phantom by SensAble Technologies and I-Feel-Mouse by Logitech) was utilised. 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.

Moreover, regarding the tactile feedback, it was demonstrated that the tactile motors of CompuTouch (one of the partners in MUVII project) gave the sensory input expected when they were integrated in a common mouse. The users got feedback on their index while interacting with a windows application and the capabilities and limitations of such tactile motors were studied in detail.

The teachers were fascinated with the idea of using haptics in their classes since this technology gives the opportunity to observe, test and simulate phenomena that could not be performed in a class or in a school laboratory (Ioannidis and Garyfallidou, 2001). This is due to several reasons such as safety problems (e.g. it is too risky to use explosives or certain chemicals in an ordinary lab) or too difficult and perhaps impossible experiments ("switch off" friction for instance, driving any type of vehicle and feel the forces of a collision, construct a certain machine etc.).

One of the primary interests during this phase was to specify the best shape and functionalities of the IKD device. The main 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. Apart from that, users expressed their interest in the use of two devices, one for each hand. Moreover, users wanted a large workspace (i.e. actual space where the device would be active).

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. Finally two applications were selected and implemented for the IKD, as described in a following section.

User Requirements Analysis

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 (but at least on the two essential ones: thumb and index). The users required to be able to *investigate and explore* various 3D objects and *feel* their material, surface, size, shape, etc. Another very important characteristic, for the educational use of the IKD was deemed to be its *realism*, (something that is normally ignored by game developers). Special emphasis was given 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 operate 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 able to easily perceive their direction, distance and volume, while at the same time they can communicate with the other users by using open air headphones. Furthermore, *Haptic related sounds* (i.e. sounds produced directly from the interaction of the user's virtual hand with the objects) should also be supported by the sound subsystem of the IKD.

One of the most challenging requirements was to support two users interacting simultaneously in the context of the same application. The users should be able to jointly manage the common viewpoint, but each user should be able to independently move inside the 3D world of the application. The two users should be able to act simultaneously either on the same or on different objects.

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.

IKD Haptic Device Specifications

The MUVII IKD Haptic 3D Interface (H3DI) is the human-interface part of the IKD platform and plays an extremely important role in the functionality of the whole system. The IKD H3DI should respect some specific constraints, regarding the various ages of the final users (children as well as adults), and some requirements that are determined by the IKD applications. The analysis of these requirements and constraints led to the following specifications:

Size of H3DI: How small should the body of the H3DI be? The main concern is the use of the device by young children (primary school). As the size of their hand is smaller, we cannot expect young children to be able to handle with ease (or at all) a device created with a fully-grown male in mind. Therefore, the best possible solution is to create a device that is *adjustable in size,* so it can be used by adults and children as well. This could be achieved by having detachable pads attached to the main body.

Weight: It should be as light as possible, approximately 100 - 150 grams. The balance of this weight is of considerable importance, as it should not be very top – heavy, or in anyway out of balance. A top-heavy H3DI would feel unnatural to use and, therefore, the user would find it hard to “immerse” in the use of it.

Priorities to be kept in the design: The *balance and fit* are probably more important parameters than size and weight. Any inevitable compromises made should keep this in mind.

Type of movements: The users should have the capacity to move their hand (with the device worn) freely in space without strict movement restrictions. Moreover, the users should be able to use at least two of their fingers (thumb and index) independently. This way, it was observed that they could easily manipulate virtual objects (albeit in a rather unnatural fashion). Taking into consideration that in this trial a new haptic interface was evolved, this is acceptable. It also turned out that the user could easily ajust him/herself to this situation, e.g. the use of only two fingers to manipulate objects). Furthermore, the precision of the movement is an important factor, because it allows the user to perceive the haptic device as an extension of his hand.

Force feedback: Users should be able to manipulate objects using their two fingers and feel forces acting on them, independently on each finger.

Tactile feedback: Users should be able to get tactile feedback (feel the surface contours and textures) on their two fingertips. For the MUVII IKD H3DI this tactile feedback is provided by two tactile motors integrated on the H3DI. These motors (see Figure 1) were developed by CompuTouch, a MUVII partner. The integration on the H3DI allows good force feedback on finger, while keeping fingertips free for tactile feedback.

Figure 1: *Tactile Motors (Courtesy of CompuTouch(WWW))*

Type of actions: By exploiting the force-feedback of the H3DI, users should be able to select, pick-up, hold, move, orient, release/place, pull/push and throw objects, while they feel forces acting on their fingers (weight, torque, collisions, etc.). By exploiting the tactile feedback users should be able to investigate and explore various 3D objects and feel their surface material, shape, etc.

Workspace: This is the actual physical space where the device would be operational (its position can be tracked). Minimum requirements are 600 mm (width), 600 mm (length), and 400 mm (height). Obviously, the greater the final workspace is, the better for the users.

Robustness: A certain amount of robustness is required especially as we envisage children using it. Ideally, it should be able to withstand a drop from 80 – 100 cm height onto a hard floor without breaking or needing adjustment or realignment.

IKD Platform Specifications

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 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 (see Figure 2) 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. These metaphors give emphasis on events that cause haptic and tactile feedback to the users, mainly through "real-world" and "non-real-world" audio cues, sound effects and visual effects.
- Rapid application development support through the integration and customization of a commercial tool (Virtools), the MUVII IKD library of predefined generic objects & behaviours and the MUVII IKD audio authoring toolkit.
- Innovative Educational Demo Applications: These applications introduce several innovative features and their primary purpose is to demonstrate the capabilities of the H3DI and to build on its functionality, aiming at the rapid adaptation of users in the characteristics (and in the way of use) of the device.

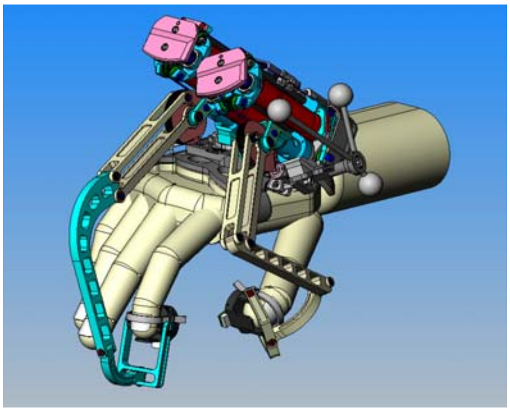


Figure 2: *IKD H3DI concept and realization respectively (Courtesy of CEA (WWW))*

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

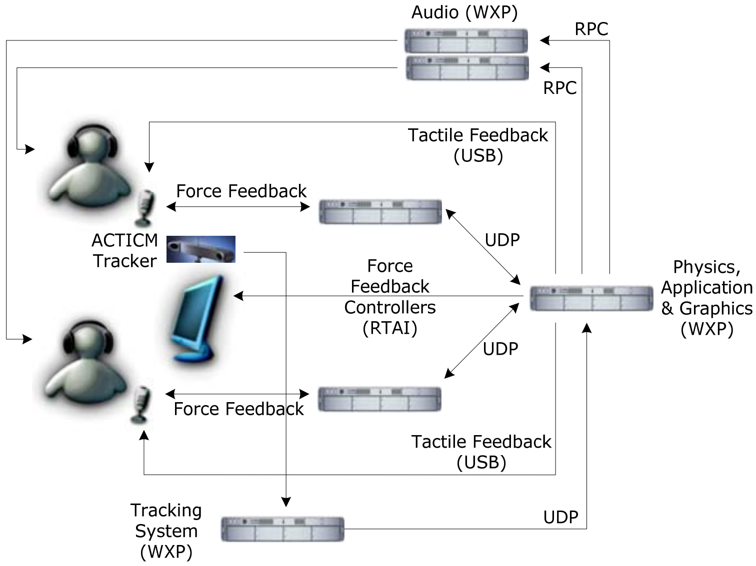

Figure 3: *IKD hardware architecture*

The really hard and technically challenging issue for IKD was to keep the latency time between visual, haptic, tactile and audio feedback as small as possible in order to achieve a great degree of realism. Very short time latency was also required for the hand tracker that was used for the accurate positioning of the real human hand and the real-time rendering of the virtual hand inside the 3D world of the application. The problem is getting harder, if you consider that these subsystems of the IKD platform are implemented by different pieces of software which are being executed in different computers and in some cases under different operating systems all connected to form a single system.

Haptics and Education

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.

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. 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." (Hayward et al, 2004).

But could haptics extend the teaching possibilities, esp. for science concepts?

Some research groups like NanoScale Science Education Research Group (WWW), investigate the impact of haptics on students' learning of science concepts, and their results so far are very encouraging. According to their research, when a student uses haptic devices receives two kinds of stimulants distinguished in kinesthetic and tactile perception. Both stimulants are dynamic, which means that they change as the user is operating the objects, no matter if they are physical or virtual. This active touch involves intentional actions that an individual chooses to do, whereas passive touch can occur without any initiating action. For educators, involving students in consciously choosing to investigate the properties of an object is a powerful motivator and increases attention to learning.

Moreover, it is experimentally proved by Sathian et al (1997) and Itan (2005) that where vision is the dominating sense in form perception (macro-geometry) of bodies, touch excels in defining their texture (micro-geometry).

Other researchers (Okamura et al, 2002) showed that 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.

IKD Educational Applications

Haptic technologies offer an enormous variety of applications starting from "virtual" school laboratories and going as far as learning auto driving, surgery, or even space ship manoeuvres. In such a virtual reality environment that supports haptics, the applications could provide the users with the capability to:

- 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.

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 analyzed 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, 2005, section 3.5). The basis of the constructivist theory of learning and instruction is formed by the writings of Piaget (Piaget, 1972 and Piaget et al 1995) and Vygotsky (1978), along with the work of Ausubel (1968) and Bruner (1990). 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. Our study showed that the knowledge remaining in the student's mind 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 listens to the teacher teach or watch a science video.

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. Figure 4 shows a screenshot of the application.

Regarding the *Virtual Model Assembly - Gears*, the user is offered a lesson of 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. Figures 5 and 6 show two screenshots of this application, the second one using the watermill paradigm.

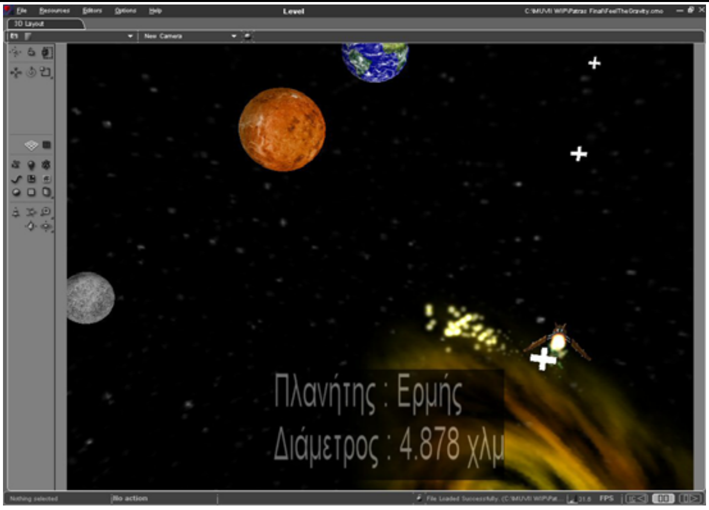

Figure 4: *Feeling the gravity*
(Planet: Hermes Diameter: 4.878 km)

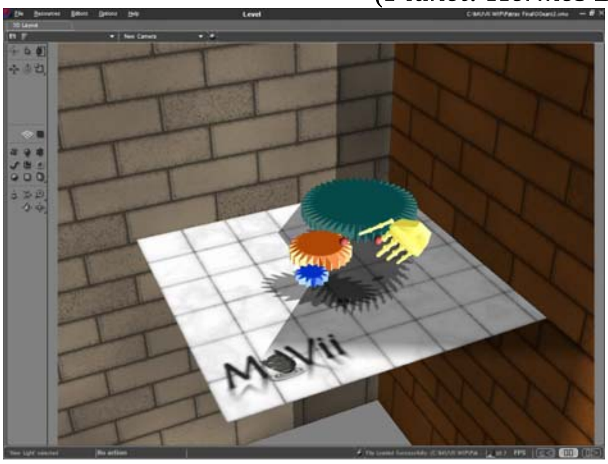

Figure 5: *Feeling moving gears*

Figure 6: *Assembling a windmill*

IKD Experimental Validation

The first public experimental validation of IKD H3DI, software infrastructure and applications, took place in May 2004 in Laval Virtual (see Figure 7 and 8) exhibition event, one of the biggest annual exhibitions in Europe for Virtual Reality.

Despite the fact that the device was aimed at children of ages above 10 years old, it occurred that even younger children (e.g. 7-10 years old) could use it effectively. During the tests in Laval the users were very enthusiastic and attracted by the device and the applications. Almost no-one gave up trying to finish the application, despite the difficulties everyone faces when coming in contact with a new technology and a virtual space he/she has to interact with. The testers were invited to write their opinion and impression about the IKD, some of which are presented here:

Kevin, 12:

I find it very good fun, and I think that this system could be used to control/test objects in space or on planets.

Christian, 36 :

Very good sensation of the movements in space and of the grapping. Very realistic force feedback. Thank you

Nicolas, 24:

Feelings almost real, impressive sensation of resistance. I think that many useful applications can be developed.

Figure 7: *Laval Virtual demonstration, a young user*

Figure 8: *Laval Virtual demonstration, an adult user*

After this initial demonstration of IKD, the educational trial of the IKD system took place, for more than three months, with an adequate sample of more than 300 pupils, and some teachers. IKD H3DI, software infrastructure and applications have been tested, against functional and performance issues, with schoolchildren that have been randomly selected from various schools of Patras and Achaia prefecture. It should be mentioned here that mostly due to the equipment size, and the 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 this educational trial **163 students** participated:

64 of which were primary school pupils,
74 were lower secondary school students, and
25 were upper secondary (i.e. lyceum) 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 were presented in (Christodoulou et. al., 2005). We summarise the most important ones below.

- A large proportion of children found teaching with the use of a haptic device interesting. 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.
- No student found the experiment boring or too difficult (which is a big compliment!).
- 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 (a questionnaire filled by students before the trial), an overall increase in understanding is obvious. This really is *"understanding by feeling"!*
- 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.
- 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.

Overall, the encouraging result from this investigation is that we can easily use IT and haptics to teach science (and perhaps other subjects) even with primary school pupils.

Conclusions

The multi-sensory environment of a haptic device can greatly improve the existing teaching methods, by offering tools of enhanced quality suitable for deeper understanding of the entities taught. Students seem to have adjusted well to the new system and have enjoyed using it. Currently there are no other applications with capabilities similar to the ones specified in MUVII project, incorporating characteristics like multi-user collaboration among students and teachers, efficient 3D-sound sub-system, targeting children of various ages, efficient haptic interaction metaphors etc.

Some significant requirements and specifications for haptic devices are outlined in this paper, mainly for applications that will be used in education. Those who seek to develop haptic interfaces, as well as application software for education, will find the specifications presented extremely useful. In addition to that, this paper will help potential users (teachers, students) become more acquainted with the use of haptic interfaces in education, understand the power (and limitations) of haptically-enhanced virtual reality educational systems, and provide some useful feedback on the prospective implementation in their everyday school practice.

References

Ausubel, D. (1968). Educational psychology: A cognitive view. New York: Holt, Rinehart & Winston.
Bruner, J. (1990). Acts of meaning. Cambridge, MA: Harvard University Press
Christodoulou S. P., Garyfallidou D. M., Gavala M. N., Ioannidis G. S., Papatheodorou T. S., and Stathi E. A. (2005), "Haptic devices in Virtual Reality used for Education: Designing and educational testing of an innovative system", Proceedings of International Conference ICL2005 (Interactive Computer Aided Learning) September 28 - 30, 2005 - Villach, Austria
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
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, (2001) ISBN 3-933146-67-4
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/
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 2007).
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
Papadakis S., Xenos M., Mitsou E., "Experiences and technical issues from the delivery of computer-based learning materials in the Hellenic Open University", Open Education: the Journal for Open and Distance Education and Educational Technology, Vol. 1, No. 2, pp. 12-28, 2005.
Piaget, J. (1972). The psychology of the child. New York: Basic Books.
Piaget, J., Gruber, H. (Ed.), & Voneche, J. J. (Ed.) (1995). The essential Piaget Publisher: Jason Aronson; 100th Anniversary Ed
Sathian, K., Zangaladze, A., Hoffman, J. M. and Grafton, S.T. (1997) Feeling with the mind's eye, NeuroReport, 8, (1997), pp. 3877–3881
Vygotsky, L.S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.
CEA - Commisariat a l'Energie Atomique (WWW), http://www.cea.fr
CompuTouch AS (WWW), http://www.computouch.no/
MUVII Web Site (WWW), IST Project: Multi User Virtual Interactive Interface, http://muvii.hpclab.ceid.upatras.gr, visited in March 2007
Nano-Scale Science Education research group (WWW), College of education, NC State University, http://ced.ncsu.edu/nanoscale/haptics.htm, visited in March 2007