# INFORMATION SOCIETY TECHNOLOGIES (IST) PROGRAMME

# INTUITION

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# Subjects taught in VR

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# EXECUTIVE SUMMARY

This deliverable serves to reinstate a broad view on Virtual Reality (VR), capturing all its constituting disciplines. The core target of this report is to establish a foundation for an educational program where all disciplines subordinate to VR technology will converge. Over the past decade(s) the field of VR became heterogeneous and fragmented, due to its multidisciplinary character. There is an enormous amount of knowledge available within the different disciplines and on various levels in depth. However, a lack of coherence urges the necessity to enhance structure in this field of technology. The progress of this integration process will be substituted by developing accurate and complete VR education programs. Four core subjects were identified: modelling, psychology, technology, and designing VR. In addition, three related subjects were identified: context, application requirements, and simulation requirements.

To answer the research question: what subjects are currently taught in VR? 111 courses have been reviewed on their contents. It proves that due to its multidisciplinary character the current available courses on VR are inaccurate, lacking important subjects and lacking an integrated overview of VR. These courses mainly focus on the technical aspects to VR, neglecting the psychological subjects such as human factors and ergonomics.

To utilize the full potential of VR, a proper education program must be offered. The currently taught courses need a broader perspective of VR to reinstate VR as a multidisciplinary field of research, with a focus on all core VR subjects. The following recommendations were formed:

1. All core VR subjects should be incorporated in an educational VR programme, with a flexible though sufficient level of detail.
2. As much as possible related courses should be available, such that various specializations are possible.
3. A combined Bachelor-Master programme should be used to cope with the amount of subjects.

Enacting these recommendations will establish a more common view on VR, overcome fragmentation and enhance the progress of the integration process in general. The recommendations will result in a positive impact on education on VR, science of VR and VR as a technology.

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# List of Abbreviations

BSc – Bachelor of Science

DoF – Degrees of Freedom

HBM – Human Behaviour Model

HVEI – Human-VE Interaction

MSc – Master of Science

VE – Virtual Environment

VR – Virtual Reality

# 1. Introduction

> Ivan Sutherland, 1965:
>
> "*Don't think of that thing as a screen, but as a window, a window through which one looks into a virtual world. The challenge to computer graphics is to make that virtual world look real, sound real, move and respond to interaction in real time, and even feel real.*" (Brooks, 1999, p.17).

What is Virtual Reality? If we would ask this question to an average individual, we would probably find an answer involving "*escaping into imaginary worlds, where anything is possible*" and "*how VR can solve every social need and change reality forever*" (G. C. Burdea, 2004, p. 463). There are a lot of misconceptions and unrealistic expectations concerning VR.

A definition of VR is given by M.A. Gigante "*the illusion of participation in a synthetic environment rather than external observation of such an environment*" (Earnshaw, Gigante, & Jones, 1993, p.3). Virtual environment (VE) is a related term, often used interchangeable with VR, referring to what has been created by computing technology.

Today, roughly three types of VR systems can be distinguished by their level of immersiveness: desktop, semi-immersive and immersive systems (Fernando et al., 2007). Where immersiveness is the level of the exclusion of the real world provided by the VR system. Desktop systems are the most simple, having a small field of view and relatively few technical requirements. Semi-immersive systems usually compose multiple screens for a wide view over 60 degrees, having quite high quality graphics and creating a much more immersive effect than desktop systems. Immersive systems have a field of view of 360 degrees. These systems have the highest immersion, isolating the user, at least visually, from the real world.

The desktop and semi-immersive systems seem to fail Gigante's definition. This is where some historical context comes in hand. The immersive systems are often referred to as the traditional VR systems fitting into the first visions on VR such as the vision given by Ivan Sutherland. The progress in developing these VR systems was mainly a technology push driven by a dream. The technical necessities to create and manage VR systems were constantly stretched to their limits which made VR development a very expensive niche.

In addition to the high costs, the immersive systems have such a high complexity, demanding the utmost capacity of hardware and software, that it proves very hard to set up and program these systems. Also, these VR systems often work with interfaces which are too difficult for anyone without highly technical knowledge to use. This implies that VR systems were only suitable for very few applications. The usability and functionality were no where in proportion to the expensiveness of the systems. This resulted in a slow down of the development in the VR field. This sector, fully immersive VR systems, is even now a very slowly developing area within the VR field (Lawton, 2006).

To enhance the applicability, the VR systems were scaled down (desktop, semi-immersive systems), less expensive and less complex, thus accessible by more people for simpler projects. Lower prices and ease of implementation have made applications affordable and accessible to users who could not have worked with VR in the past, such as, artists, students, and engineers (Lawton, 2006). Especially the, relatively very low-cost, desktop systems, became very popular because of these reasons. These systems in particular and their growing technical abilities create a focus on graphics, being next to audio the only output device.

These scaled down VR systems increase the importance of other related subjects, such as human factors, in order to identify which functions are most important for which user experience. Here the intended use of a VR system should be highlighted, as underlined by Burdea (2004, p. 463): "*The most longevity and success has been shown by programs that are designed to satisfy a social need*". The intended use and user experience are both dependent on the type of VR system.

The scaled down VR systems, especially the desktop systems, gained popularity because of the applications in the entertainment sector, leaving the other application sectors with relatively far less attention. This becomes obvious in the following: "*Most people are familiar with the role VR plays in entertainment (such as virtual sets for filming, VR arcades, virtual museums, 3D video games and so on). But current VR applications span a much broader spectrum, from car virtual prototyping (and marketing), to surgical trainers, to distance learning environments, and others*" (G. C. Burdea, 2004, p. 464). With a view to education, this wide span of applications results in an amount of core and related subjects important to VR apart from merely graphics design on which the current education programs are mainly focused. Most scholars have not adopted this broader perspective on VR. For example, Zara (2006) states that courses in VR are "*a natural enrichment of computer graphics classes*" (p. 105). However, when describing VR solely from the perspective of computer graphics, a vast amount of characteristics is ignored. Among the subjects one should denote issues such as human factors, interface design, arts, and architecture. Simply put, there is little awareness of the amount of disciplines captured in VR, which results in inaccurate educational programs lacking important subjects. To illustrate the multidisciplinary character of VR an example is given.

Pouliquen, Bernard, Marsot, and Chodorge (2007) present a virtual hand, used to interact with a virtual environment developed to design safer industrial systems. This VR system simulates an operator-machine-environment. The designers are enabled to asses different concepts on a deeper level preceding to manufacture; e.g., the machine safety can be checked and a workforce can be trained in doing several tasks with the machine. A set of parameters is essential to obtain a realistic simulation with VR-techniques; e.g., a realistic hand-model, real-time frame rates and accurate dynamic models. This implies there are many subjects of great importance to create the described VR system. This can be illustrated by a quick peak at some of the used references: the journals Computers in Industry, Computer Graphics, and Safety Science; conference papers about modern design theory and the methods and tools of virtual engineering; the books Atlas of Human Anatomy and Safety Engineering; and so on. As can be seen, many references are applied to a specific field or only relevant to a specific problem, whereas others are core to any VR system.

If we want to utilize the full potential of VR there is need of an educational program were a more common view on VR is adopted and all disciplines constituting VR are taught. Therefore the main question of this article is: what subjects are and should be taught on VR?

To answer this question, first a determination will be made of the different subjects which are essential to VR. These subject will be divided in core and related subjects. Furthermore illustrations will be given to underline the multidisciplinary character of VR. After having described what subjects should be taught a review will be given on which subjects are taught, from which recommendations will follow.

## 2. An overview of VR subjects

The field of VR is very wide, constituting of many different subjects from many different disciplines. It is simply impossible to elaborate on every subject into far detail, since a book can (and often has been) written about every aspect of every single subject. Therefore the different subjects have been categorized. The result of this categorization is summarized in Table 1.

This list of subjects has been based on various literature, stemming from overview books on VR, articles about various specific aspects, and descriptions of applications.

In the following paragraphs an overview will be given on the various core and related subjects constituting VR. As mentioned above, not every subject can be discussed in full detail. Therefore, the reader is referred to additional available sources for more information about these subjects. On a number of aspects of subjects, an elaborated view will be given in the paragraphs associated with the subjects in Table 1.

*Table 1: Summary of core VR subjects*

| *Core VR Subjects* | |
|---|---|
| Name | Elaborated topics (paragraph) |
| Modelling | |
| Geometry | |
| Simulation | |
| Aural and Haptic Modelling | |
| Autonomous Virtual Actors | Autonomous virtual humans (2.3.1) |
| Psychology | |
| Human Factors and Ergonomics | Human Information-processing (2.3.2) |
| VR Experience | |
| Psycho(physio)logical Measurement | |
| Technology | |
| Hardware | Data gloves (2.3.3) |
| Software | |
| Technical Integration | |
| Designing VR | |
| Development Approaches | |
| Virtual Art | |
| Interaction Design (HVEI) | Usability Engineering (2.3.4) |
| *Related VR Subjects* | |
| Context | |
| About VR | |
| Culture of VR | |
| Philosophy of VR | |
| Application requirements | |
| Simulation requirements | |

## 2.1. Overview of core subjects

Following is a short and abstract description of the core subjects.

**Modelling** is the most ancient VR subject, being the concept behind VR as a natural enrichment of graphics classes (Zara, 2006). Some might even define this subject as "describing the concept of 3D graphics", but this subject goes beyond just modelling the graphics of the virtual worlds. It taps into other aspects as well. The subject consists of various subtopics, from which the following will be discussed shortly: geometry, physical simulation, haptic and aural modelling and autonomous virtual actors.

Geometry is used to model the graphical aspects of the real world into the virtual world. To achieve this some basic geometrical concepts are needed for VR, such as the perspective of the virtual observer (e.g., field of view), adding textures, and stereoscopic images. When a virtual world has been modelled, the need exists of altering it. This is referred to as kinematics, meaning transforming the geometrical objects regardless of any rules such as physical constraints. Kinematics consists of techniques such as free form deformations, a technique commonly used to transforms geometric forms (Coiffet & Burdea, 2003).

In contrast to the mentioned kinematics, where the physical constraints were ignored, the need obviously exists to model these physical constraints. Topics such as collision detection and force computation are relevant to let the virtual world behave in accordance to the real world. In order to model the real world physics, obtaining knowledge about natural science is a necessity. Several models have been based on, for example, Newton's laws of physics. More information can be found in Coiffet and Burdea (2003).

When modelling an immersive virtual world in accordance to the real world, modelling graphics alone is not enough. Haptics and aural modalities are essential for creating an immersive virtual environment. This requires more knowledge about the virtual world, such as modelling what sounds and forces should be generated by virtual objects. Furthermore, several attributes of sounds and forces are dependent on the geometry of the virtual world, namely for generating 3D sounds (where did the sound originate from?) and for generating haptics (when does the user touch an object?). For more information about modelling 3D audio and haptics the user is referred to Sherman & Craig (2003).

A special issue in VE's is the modelling of Virtual Actors. This is not only an enrichment on, and application of the already discussed geometrics and kinematics, but taps into other issues as well. For example how virtual actors should act (Perlin, 2003) and interact (Nijholt & Hulstijn, 2000) with each other and with real humans. Concerning modelling techniques and virtual art, special care is given too, amongst others, tailoring the clothes of virtual actors (Ng & Grimsdale, 1996) and giving them detailed facial features (Kähler, Haber, & Seidel, 2001). Developing autonomous virtual humans which are similar to real humans is a very difficult undertaking, not only in the graphical aspects but also in giving them artificial intelligence. The behaviour of virtual humans is further elaborated on in paragraph 2.3.1.

**Psychology** lays at the heart of VR. Looking at the history of VR, where VR is mainly viewed from a technical point of view, this statement needs some explanation and can be seen as a recommendation concerning the VR subjects that also should be taught. Historically, computers in general and VR in specific have been created from a technological possibility neglecting psychological aspects. Only more recently humans have become more important, since humans seemed to become the limiting factor in system design and task performance (Schraagen, 2006). This is most certainly the case for VR systems because of their complex nature. Any VR system should consider, amongst others, the following psychological subjects: human factors and ergonomics, VR experience, and psychological measurement. These subjects are core subjects for VR. There are other psychological subjects also of importance to VR (e.g., those used for simulating humans). These are considered related subjects and are only relevant when modelling a specific part of the real world.

Human factors and ergonomics consists of the (dis)abilities of the human to act with and within a virtual system. Human factors and ergonomics is the term used for the application of fundamental knowledge about the human on the development of systems. This mostly concerns certain areas of cognitive psychology, such as attention, perception, memory, emotion and language processing (Wickens, 2000). For example, knowing how the human perceives depth, knowing how multimodal integration occurs or knowing the limitations of humans concerning their perceptual or cognitive load and attention is very relevant for VR. Some more details on attentional resources, multimodal integration and emotions are given in paragraph 2.3.2.

The second category, VR experience, is about the user's experience when using a VR system: the experience of presence and immersion, or more negative: the experience of nausea (health and safety issues) (Stanney, Mourant, & Kennedy, 1998). Furthermore, the Abstraction-Realism continuum belongs to this category, in defining the level of realism (e.g., immersion) necessary for a certain user experience (e.g., presence).

Finally, measuring human factors is a subject necessary for anyone who wish to obtain a broad mastering of VR: in order to know anything about any user concerning your system, it has to be measured. This can be used for multiple application as well, such as knowing the user's emotional state and having the VE act upon it (Broek, Schut, Westerink, Herk, & Tuinenbreijer, 2005).

**Technology** is one of the classical key subjects of VR. In this review, it is divided in three categories, being: hardware, software and integration issues concerning the various modalities and input and output channels.

Hardware is commonly viewed from an input and output perspective. Input devices being tracking systems and devices for text, graphic, auditory input and gesture recognition (e.g., hand gloves, further described in paragraph 2.3.3). Output devices being display devices (e.g., projection technology, head mounted displays), and devices for the auditory, haptic (e.g., forces) and vestibular channel (e.g., a car simulator). As can be seen, many devices are available for VR, each having their own characteristics and producing their own data or experience. For a thorough review of the state of the art in VR devices one can view Fernando et al. (2007). Knowledge about devices is necessary for the development of a successful VR system. A VR system not only consists of hardware devices for input and output, but also of architectures that control them. One of the main architectures is called the rendering pipeline, consisting of stages to create 2D displays from 3D images. For an overview of the architectures relevant to VR the reader is referred to Burdea & Coiffet (2003).

Software packages make it possible to program the hardware architectures and devices. Several packages exists, such as Java 3D, WorldToolKit (WTK), GHOST, PeopleShop and 3D Game Studio, OpenGL, and many more. There's also one popular standard available for defining 3D vector graphics, namely VRML. This standard is supported by various of the software packages mentioned, such as Java3D. The user is referred to Fernando et al. (2007) and Burdea & Coiffet (2003) for more information.

One of the main technological problems in VR is the overall integration. Namely, the synchronisation between input and output, in other words temporal latency. As Brooks (1999, p.19) states it: "*end-to-end system latency is still the most serious technical shortcoming of today's VR systems*". Technologically advanced algorithms are needed for recognising input (e.g., using neural networks) and to predict future movement of the user to reduce the temporal latency.

**Designing** a **VR** system is a multidisciplinary undertaking, putting into practice all the subjects described above. The following topics concerning design will be discussed: developmental approaches, virtual art and Human-VE Interaction design.

"*Design can be described as the process of taking a number of often conflicting criteria for the creation of an object such as form, function, cost, and manufacturability and marrying these together to form a whole*" (Davies, 2002, p. 1079).

Developmental approaches to VR design are sparse. In contrast to, for example software engineering, where many approaches exists on how to create complex software systems. These approaches are, nevertheless, not applicable to VR because of the complex nature of VR. The need for such approaches does exists, considering the large amount of issues coming with every VR system. Some models do exists though, of which Virtual Environment Development Structure (VEDS) is one of the most salient. A thorough description of VEDS can be found in Eastgate (2001) and Wilson, Eastgate, and D'Cruz (2002).

Virtual art is the art of bringing modelling techniques to life. Knowing how one can technically model some aspects of the real world does not implicate one actually can model them, at least not in a coherent fashion. This topic cannot be viewed purely from an engineering point of view, but requires the need for artistic skills and knowledge. For the designing of 3D objects, several methods currently exist, ranging from 3D drawing programs (e.g., 3D Studio Max), through 3D scanners to databases containing 3D objects (G. Burdea & Coiffet, 2003). Besides graphics, other aspects of VR need to be designed: haptics (3D form and touch), auditory (sounds and music), filmic (narrative, animations), and literary (prose, dialogue).

Next to designing the artistic aspects of a virtual environment, the interaction between the virtual environment and the user has to be designed, also referred to as Human-VE Interaction (HVEI). HVEI is the field of interaction design with an enormous amount of possibilities. For a start, there are many possible interfaces: ways to let a user give input to the VE and ways for the VE to give output back to the user. An example of an input interface is the use of hand gestures to control the VE (Vaananen & Bohm, 1993). Furthermore, there are many types of interaction, the most important being manipulation, navigation and communication (Sherman & Craig, 2003). In knowing the possibilities of HVEI it is natural to look at ways to evaluate these possibilities and identify best practices. This is, finally, what usability engineering and human performance studies are about. The latter concerns human performance with tasks in a

VE (Stanney et al., 1998). The prior concerns design guidelines and methods to heighten this performance (Hix & Gabbard, 2003). Some concepts and implications of usability engineering are further described in paragraph 2.3.4.

## 2.2. Overview of related subjects

Next will be an overview of the related subjects, similar to the overview of core subjects.

**Context** is used here to describe all subjects which consider the whole field of VR as a topic, and are thereby more concerned with the causes and consequences of VR than any of the specific elements that constitute VR. The following subjects will be discussed as context: “about VR”, culture of VR, and philosophy of VR.

About VR is a collective noun for information about the history of VR, the definitions of VR and the types of VR. The history of VR is commonly thought to start in the early 1960’s, with as one of the first publications: “Sketchpad: a man-machine graphical communication system” from Ivan Sutherland (1964), describing a concept for a HMD which he later put into practice. VR has had some major progress in the following decennia, like hand-gloves and greatly improving graphics. In these decennia, many forms of VR have seen the light: from the generic full immersive VR system to the semi-immersive or desktop systems, and from full VR to forms of mixed reality: augmented reality (adding information to the perception of the real world) and augmented virtuality (adding objects or humans from the real world to the virtual world) (Milgram & Kishino, 1994). The work done in VR has brought about at least 173 different terms, definitions and abbreviations (Blade & Padgett, 2002), all currently used and thereby being valuable related knowledge.

VR has brought about a culture and social impact as well. Currently one of the most popular implementations of a VE is Second Life[1], where users can act out another character in a VE. Second life has a large virtual community, which has expanded to more than 4,5 million residents at this point. Furthermore, various (real world) organisations are currently opening virtual portals for their organisation in Second Life, such as the city of The Hague, the Netherlands, which has recently spent €17,000 to a virtual beach-bar (Verbaan, 2007). Such evolvements have even created protest groups, among which First-Enschede[2], stating that a first, real, life is better than any second life. The social impact of VR cannot be ignored any longer, and several papers already address social consequences of VE’s (e.g., Calvert, 2002).

Philosophically VR raises an important question, namely, what is reality? The expression virtual reality is, in its essence, a paradox, a contradiction in terms, and in that sense directly addresses the raised philosophical question. People have, in line with this, always strived to create another world, which becomes obvious from an art history point of view. This is perfectly illustrated by the book title “Virtual Art: From Illusion to Immersion” (Grau, 2003), and perfectly shows the wealth of the context of VR.

**Applications** of VR are numerous, and beyond the scope of this overview to describe all of them. This has a positive side, implying VR is a technology which is used in

[1] www.secondlife.com

[2] www.first-enschede.nl

many sectors. Some of the applications will be reviewed, in order to capture some of the specialised subjects required for them. The applications are separated in traditional and emerging applications, adopted from Burdea and Coiffet (2003).

Traditionally, VR has been mainly used for training and education, followed by research, business services, entertainment and communications. These applications all bring some new requirements to the related subjects of VR. For example, training and education focuses on how to train or teach people using VR. The concept of transfer of knowledge is very relevant for this application, being a quite comprehensive research topic on its own (Singley & Anderson, 1989). This concept has been put into practice in, amongst others, medicine. For example, surgical residents have been trained in suturing skills using a VR simulator. The transferability of this training have been tested on a porcine model, showing significant improvements for the VR simulator above normal training methods (Korndorffer et al., 2005).

Emerging applications are applications primarily in manufacturing (especially virtual prototyping, assembly verification, ergonomics, and marketing), robotics (programming, teleoperation, space robotics), and data visualization (volume visualization, oil and gas exploration, volumetric displays). Especially the design of large and complex systems can benefit from VR, such as the design of a vehicle. VR can assist in the design of vehicles by supporting concept formulation (e.g., the design's wind drag coefficient), by planning the construction sequence, and by testing assembly and part fit. In this way, VR can save development time and money and increase quality by reducing the need to build physical mock-ups (Davies, 2002). Of course, it is trivial that enabling the design of a car in a VE requires knowledge from very specific domains of engineering and usability.

**Simulation** of the real world into a virtual one brings about a lot of related subjects. The goal would be to give a complete overview of which related subjects are required for the simulation of specific real world items. But, in its definition this goal is unreachable. When simulating a world, all subjects describing something of this world are relevant. Considering the real world as we perceive it, this is an infinite list of subjects describing an infinite number of items. In order to still give an overview, the simulation of various parts will be considered, being: human, fish, lightning, motion, and music instruments.

Considering the human, many topics are to be simulated. The appearance and motion of the body, face, cloth and hair. Subjects from physics (motion), mechanics (e.g., as an approach to cloth simulation), biology (e.g., reflexes and anatomy) become relevant. The behaviour of humans will be described more detailed in paragraph 2.3.1. Subjects from psychology, art media and sociology become relevant for behavioural modelling. Finally, communication taps into linguistics (e.g., meanings, facial expressions) (Magnenat-Thalmann & Thalmann, 2004). For the modelling of a fish, similar topics are relevant: a physically based method for body movement, a model of schooling behaviour, etc. All using knowledge from biology (Lobb & Bangay, 2003).

Lightning and motion are typical topics addressed by physics. For example, collision detection has borrowed knowledge from physics about physical laws and physical properties of objects (Willis, 2004). For common motion, laws have even been borrowed from ancient Aristotelean physics, with a believe these laws give more natural looking motions (Poston & Fairchild, 1993). And finally, liquids and even steam has been simulated according to real-world physic (Cavazza, Hartley, Lugrin,

& Bras, 2004). Another practice of modelling is the modelling of virtual music instruments (for an overview, see Smith, 2005). By using knowledge about acoustics and electronics, a virtual electronic guitar and a virtual xylophone have been created (Karjalainen & Maki-Patola, 2004).

As can be seen from this small overview of simulation topics, many subjects become relevant when simulating specific parts of the world, even as small as a fish.

## *2.3. Elaborated views*

Some of the subjects above have been selected to look at in further detail. Since it is infeasible to describe all subjects and all topics accompanying them in detail, a limited selection has been made. The focus is given to those subjects that are multidisciplinary or have received the least attention in VR, in order to elaborate on their key relevance to VR. Table 1 gives an overview of the topics which are given an elaborated view.

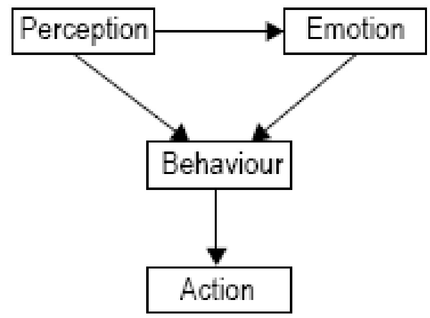
### 2.3.1. Autonomous virtual humans

A large research topic within computer simulation in general and VR in specific is the creation of autonomous virtual humans. A continuous problem with virtual humans is that they don not act like real humans (Perlin, 2003). A recent literature review identified: "g*enerating complex behaviours of virtual humans inside their environments using a realistic perception of the environment*" (Magnenat-Thalmann & Thalmann, 2005, p. 999) as one of the biggest challenges of virtual humans. Complex behaviours can be generated at three levels of autonomy, each needing an increasing level of artificial intelligence and each being able to act more realistic: guided, programmed and autonomous behaviour. This is where Human Behaviour Models (HBM) become relevant, being implementable models of realistic, autonomous behaviour (Thalmann et al., 2000).

As identified by the quote, perception of the (virtual) environment is one of the most important parts of a HBM. A typical behavioural model has been developed by Thalmann et al. (2000), which will be discussed here. This model consists of four interleaved modules (see Figure 1): perception, emotion, behaviour and action, in such a way that perception can create emotion, and perception and emotion influence behaviour which influences action.

Perception being the key element for a HBM makes it require more attention. An agent needs visual, tactile and auditory sensors in order to simulate everyday human behaviour, such as visually directed locomotion and responding to sounds. Typically not everything can be perceived, just like humans direct their attention to certain objects or actors in their environment. This has been modelled as well. There being three types of perceptions: one of the presence of objects and actors; one of the actions of actors; and one of performing actions on objects. As said, humans do not perceive everything but select what to perceive by directing their attention. Attention has been modelled by some studies as well (Khullar &

*Figure 1. Human Behaviour Model. Adopted from Thalmann, Musse and Kallmann (2000)*



Badler, 2001; Rymill & Dodgson, 2005a), although its effect on behaviour is still open.

Emotion is commonly viewed as a person's reaction to a perception. Thalmann's HBM implements emotion with this view, in line with a classical view of emotion as being reactions from objects, agents' actions and events (Ortony & Turner, 1990). Emotions can then be categorized in three groups, dependent on their emerging conditions, from which a virtual agent can handle upon them. In this way human emotions can be modelled as to create more realistic virtual humans. Though emotion is still an extensive research topic, certainly in relation to perception and behaviour.

The tasks of handling upon emotions and perceptions is modelled by the behaviour module of Thalmann's HBM. Behaviour is described in a hierarchical way, each behaviour decomposing into simpler behaviours until eventually a set of performable behaviours is reached. These are then executed by the action module, which manages the execution of the behaviour.

Thalmann's HBM gives a perfect view of how behaviour can be modelled in a VR system. Though various parts of behaviour can be modelled in more detail, several attempts have been made to give virtual humans a more realistic look, by using psychological findings. One of those attempts has already been mentioned, being gazing behaviour. Another of those attempts, concerning walking, is described in

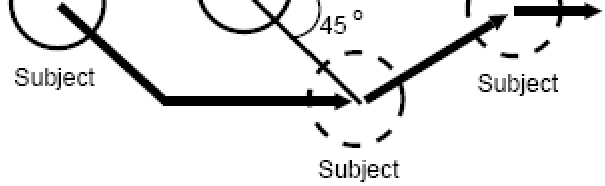
*Textbox 1: How (virtual) humans walk*

Behaviourally, humans tend to walk ways dependent on their environment. In other words, usually we won't bump into each other or walk up a wall. One specific element of this, collision avoidance between humans, has been modelled based on psychological theory.

Psychological theory shows people tend to avoid an oncoming collision late in high-crowded situations (app. 1.5m), compared to early in low-crowded situations (app. 30m). Several techniques exists for the actual avoidance, being detouring when noticing it in time and subtle step-and-slide when noticing it late. In the same way, when a collision is predicted with a human walking in the same direction, there are two options: overtake or slow down and walk behind. This choice is also dependent on the crowdedness of situations, where in high-crowded situations it's harder to overtake.

These, and more detailed findings, have been implemented in a series of algorithms predicting a collision and a series of rules on solving them. For example, figure 2 shows how an overtake is acted out by a virtual human (Rymill & Dodgson, 2005b).

*Figure 2: Behavioural model of overtaking another human. Adopted from Rymill and Dodgson (2005b)*



more detail in Textbox 1.

In the strive to giving virtual humans more and more realism, Perlin (2003) coins another term: believability. People tend to have a “willing suspension of disbelief” which allows them to easily pretend an actor is experiencing some inner psychological state. But, when an actor is using canned movements over and over again, the disbelief will in fact reoccur. Bugs Bunny is a relevant actor in this case, as everybody believes Bugs Bunny has a psychological state (e.g.,, his attitudes and how he will react to new situations). In other words, Bugs Bunny is more believable than many virtual humans, though his realism is much less.

Bugs Bunny perfectly illustrates how very specific issues are involved in a specific part of virtual environments. It involves not only real human behaviour in order to simulate it, but also how real humans perceive imperfectly simulated virtual humans.

### 2.3.2. Human Information-processing

Today's complex technology requires a perfect match between systems and the people who operate them. To develop safe and effective human-system interaction, one has to know both what is required from a technological perspective, and what are the possibilities and limitations from a user-based perspective. Historically, the latter has been the primary object of study for ergonomics, which could be defined as the application of scientific information concerning humans to the design of objects, systems and environment for human use. However, as systems are rapidly growing more complex, more fundamental insight in human information processing is required. This calls for a synergy of ergonomics and cognitive psychology.

Cognitive psychology involves the experimental study of human information processing in its many manifestations such as attention, memory, language processing, emotion, and perception. Historically, these are all highly interrelated subjects of fundamental research. However, a more applied perspective with regard to these topics seems rewarding. Below, we will outline the (potential) significance of fundamental insights into human information processing to the field of ergonomics. The following topics of cognitive psychology will be elaborated on: multimodal perception and spatial memory.

**Multimodal perception**. One could say that perception involves a process between an agent and an environment to collect information about the environment, relative to the agent. Modern VR systems are mainly developed from a graphical point of view. However, in every day life we encounter and use much more sensory input, such as sounds and haptic feedback. When we are trying to model the environment we are living in, graphical simulation will not be sufficient in many cases: we are living in a multimodal world. Multimodal presentation has been identified as one of the elements of presence: having cross-modality matching increases feelings of presence in a VE (Sadowski & Stanney, 2002). An example of cross-modality matching is given in Textbox 2.

There is a lot of evidence for an advantage of multimodal perception over unimodal perception. For the auditory and visual modalities used primarily in current VR systems there are several bimodal advantages. For example, when considering speech, the visual-auditory modalities are complementary on individual phonetic features (Robert-Ribes, Schwartz, Lallouache, & Escudier, 1998) and are synergetic: combined auditory-visual perception is superior to perception through either audio or vision alone (Erber, 1975). Effects on memory and emotion have also been shown. Though, these benefits are not simply given when using both modalities. Several criteria influence these effects, mostly in an all-or-nothing fashion. Three of the criteria of bimodal combination will be discussed, being spatial, source and temporal coherence.

Spatial coherence, also known as the ventriloquism effect (Vroomen & De Gelder, 2004), should be sufficient in order to ascribe heard speech to a seen face. Considering the robustness of this effect, the probability of losing the ventriloquism effect is very small for VR systems.

Source coherence should be sufficient to achieve any benefits and to prevent a McGurk effect (McGurk & MacDonald, 1976) from occurring. This effect basically describes the finding that people misinterpret several phonemes when presented slightly erroneous visual stimuli. In the case of speech, this implies the lips should follow the speech closely, which is quite a challenge for VR modelling to achieve.

Finally, temporal coherence between the auditory and visual modalities should be within sufficient ranges. Summerfield (1992) concludes an auditory delay of at most 80ms has no effects on intelligibility, though different researchers find different results (e.g., Dixon & Spitz, 1980). Most differences come from different stimuli and methods, and considering temporal latencies are one of the main technological problems in VR systems, temporal coherence is more than relevant for VR.

**Emotions** are important determinants of human behaviour and highly involved in social interaction. Cognitive psychology has focussed on this role in human information processing. One study from cognitive psychology will briefly be discussed, namely the recognition of emotion based on physiological signals.

The recognition of emotional expressions can help VR systems to recognize and respond properly to their user's emotional state. As a first step to a system that recognizes emotions of individual users, Van den Broek et al. (2005) investigated the relation between emotional experiences and six parameters (mean, absolute deviation, standard deviation, variance, skewness, and kurtosis) of physiological measurements of three electromyography signals: frontalis (EMG1), corrugator supercilii (EMG2), and zygomaticus major (EMG3). Some of the measures succeeded in distinguishing between emotion categories (neutral, mixed, positive). Hence, they might someday provide computers with the means to sense the emotions of

*Textbox 2. Visual-tactile multimodality.*

Whereas visual and auditory stimulus presentation is well advanced and relatively easy to simulate, tactile simulation of the real world is a different case. Throughout its technologically development, however, insight in fundamental cognitive processes may assist in doing so effectively and efficiently. Gepshtein, Burge, Ernst and Banks (2005) investigated the inter-modality binding problem for vision and touch. They presented visual and haptic information separated by different spatial distances and compared human performance on a discrimination task. They found that visual and haptic information coming from different spatial locations, even though hardly noticeable, is not being perceived as coming from the same object. So, it seems that for the nervous system to combine visual and haptic information about object properties, spatial coherence is essential.

their user. Overall, this study provides a good example of the possible application of fundamental psychological tools and outcomes to VR systems.

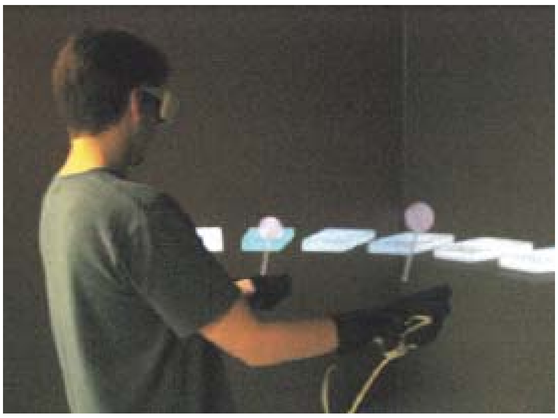
### 2.3.3. Data Gloves

Data gloves is another topic on which an elaborated view will be given, as a reflection of the technical aspects concerning the VR field. Data gloves are a typical VR input device, being a device with remarkable natural interacting possibilities. First developed by D. Sandin in 1976 this device has been produced in various different types, all attempting to at least measure the hand's movements. The version of D. Sandin, the "Sayre glove", used flexible tubes parallel to each finger with a light source on the one side and a photocell on the other side, giving a decreasing amount of light passing through when a finger is bent. In 1987 the actual DataGlove was developed by T. Zimmerman and others, monitoring 10 finger joints and 6 DoF's (degrees of freedom) of the hand's position and orientation. The characteristics of later developed gloves were further improved, having higher temporal resolutions and higher accuracy in measuring smaller hand and finger movements (Sturman & Zeltzer, 1994).

Four sensor techniques are currently used for data gloves: acoustic, optical (e.g., the "Sayre glove"), magnetic and resistance tracking techniques. Each of these techniques having their own characteristics and being a subject of their own, a lot of knowledge is necessary about them to use them, and even more to develop them. Dependent on the possibilities of the techniques, very large amounts of data have to be analyzed in order to be able to use a glove, all in more or less time-critical situations. And, the more measurements (e.g., more DoF's, more joints) the device will have to make, the less portable it is going to be (Fahn & Sun, 2005). All these different developmental issues point out the amount of subjects accompanying the successful use of a data glove, and point out this use should be defined beforehand.

Having such devices available creates many possibilities for interaction design. (Hand) gesture recognition is one of the particular interesting possibilities, to let the user interact using natural or specific gestures. Several methods for input analysing have been defined: rotoscopy, direct metaphors and recognition-based metaphors (Earnshaw et al., 1993). For data gloves, two of these methods are mostly used. First being rotoscopy, where the virtual hand is a real-time simulation of the real hand. This has been put into practice in, amongst others, the act of man-machine design described in the introduction (Pouliquen et al., 2007) and in the playing of virtual musical instruments (Karjalainen & Maki-Patola, 2004). Figure 3 displays an example of how data gloves are used in the playing of a virtual music instrument.

*Figure 3. Playing a virtual xylophone using data gloves. Adopted from Karjalainen and Maki-Patola (2004).*



One of the main challenges in rotoscopy interaction is the adding of haptic feedback. One can imagine, when touching something virtual, one misses any feelings normally accompanied with touching. Several prototypes supporting this kind of feedback have been created. An example is from Kron & Schmidt (2003), who have extended an exoskeleton supporting hand force feedback with tactile and kinaesthetic feedback. This is done by adding tactile fingertip feedback modules to every finger, producing vibtrotactile and thermal stimuli. The vibrotactile feedback is generated by a mini DC-motor with a freewheeling out of balance mass. The temperature feedback is generated using four Peltier-elements (basically electrical heat pumps). This device has been tested on users for their recognition scores of multiple types of surfaces, with a setting where they were tested on matching a real-world with a virtual surface. Results ranged from 60% (for foam) to 90% (e.g., sandpaper).

A second used method for interacting through hand gloves is one of recognition-based metaphors. A lot of research has been performed in the recognition of hand gestures. Some studies have investigated this with neural networks in order to come to a natural sign language for interaction. These neural networks gained recognition scores of 100% with training and generalization, by connecting certain output states (e.g., fist) to certain input states (e.g., hand and wrist position, middle finger bending) (Weissmann & Salomon, 1999).

As can be seen, these gloves created many possibilities, challenges and issues not only in the hardware field, but as well in software, interaction, and human factors.

#### 2.3.4. Usability of VEs

The VR development used to be mainly technology pushed, producing the new ‘gee whiz’ gadgets, with very little usability-focused research. Gabbard (1997) brings a daring statement to the table: “*unsubstantiated claims of improved performance and user satisfaction are based at best on user interface guidelines and at worst on warm fuzzy feelings of VE developers and ‘way cool’ comments from VE users*” (p .2). This lack of usability engineering resulted in VR systems with high complex interfaces, merely usable to highly trained or technical knowledgeable users. Today the development in the VR field is more use- and need-base oriented. VR systems, having a higher applicability, are now accessible to more people; this increases the necessity of usability design, and lays a focus on human interface interaction.

To create a successful VR system, the system must be usable. This sounds simple enough, but it holds a whole research area: usability engineering. Usability engineering is an interaction between design and user evaluation. In context to VE’s, applications are root to usability evaluations, where the applications are represented by the users’ tasks. In general there are three parameters to evaluate the usability of a product: effectiveness, efficiency and satisfaction. Translated to VE’s, the usability evaluation can be described as an examination of user performance and satisfaction, physical device support, and software facilities in support of users’ cognitive organization of the users’ tasks (Hix & Gabbard, 2003).

Because of the widespread applicability of VE’s, their potential task space is enormous. Therefore it is important to perform a user task analysis to identify basic task characteristics and elementary VE tasks (such as navigation, object query, object manipulation and object creation and modification). In view to task performance the nature of the tasks (real or virtual tasks) and the relationship between these tasks must be identified as well. In general the following is handled: in order to enhance task performance the user must be enabled to determine the relationship between:

- Intentions and possible actions
- Actions and effects on the system
- System status and perceptible system status
- Perceptible system status and users' expectations

The reversed version of these statements can be used to determine whether a task is suited for VE's: understanding the relations between real-world tasks characteristics and their corresponding virtual task characteristics is key to determining how well a task is suited for VE's (Gabbard, 1997).

The users' characteristics are of great influence on the design of VE's; the VE design must be adapted to the physical and cognitive capabilities and limitations of the potential users (such as user experience, domain knowledge, technical aptitude and age and gender). Which specific characteristics must be used is dependent on objective measures of task performance on which they have significant effect. The basic attributes of task performance are: task completion time, task error rate and task learning time (Lampton, Bliss, & Morris, 2002). Using this definition of task performance, the quality of a VE can be assessed by determining the relation between system characteristics and human performance.

A correlation approach used to determine characteristics of human system variables assessed by subjective measures. Measures of interest would be those that measure human system variables, e.g., sense of presence and motion sickness.

This short review of usability engineering showed: when tasks are suitable for virtual environments; which user characteristics influence task performance; what basically constitutes task performance; and which relationships between real and virtual world any VE should make clear to the user in order to enhance user performance.

# 3. Review and recommendations on current VR education

The latter two chapters described how historically the field of VR has changed over years, abandoning the dream it first pursued and focussing on more specific topics such as graphics. VR as a technology seemed to disappear, partly expected due to the breadth of the subjects covered by VR. Furthermore the multidisciplinary character was lost when focussing solely on specific aspects of VR. Education is one of the key solutions of reinforcing VR to its full potential. As such, the main question asked and answered in this paper is: what questions are and should be taught on VR?

## *3.1. Review of current VR education*

In order to evaluate the current educational programmes, the subjects core and related to the field of VR have been identified, answering the second part of the main question (i.e., what subjects should be taught). The subjects have been divided in four core categories (modelling, psychology, technology and designing VR) and three related categories (context, application requirements, and simulation requirements).

Having identified what subjects should be taught on VR enables a structured view of which of these subjects are currently taught, enabling the answering of the first part of the main question (i.e., what subjects are taught). For this, multiple courses were reviewed. A listing of 182 courses in VR from 19 European countries was used and updated, including references to further information about each course (D'Cruz & Patel, 2005). The updated list can be found in **Error! Reference source not found.**. From this list, 111 courses were actually reviewed (61%). The other courses were not available anymore, indicating quite rapid changes in VR teaching. The review was done using online sources about each individual course. The information supplied about the courses was classified into the four core and three related subject categories of VR.

The results of this review are summarised in Table 2. This summary is based on the subjects and the total number of courses teaching these subjects in more or less detail. Considering nearly all courses teach more than one subject, the sum of courses for each subject is higher then the overall sum of courses. Furthermore, regarding the related subjects of applications and simulations, only the total number of courses teaching anything about these subjects are shown. Any further specification of these subjects would be discursive and irrelevant.

These results clearly indicate a large focus on technology and (primarily graphical) modelling. Design subjects and psychological subjects are clearly less well represented in the teaching of VR. VR still seems to be taught from a technological push, with the focus mainly on the technical possibilities. Though, also indicated by the results, the possible applications are quite well represented. Sadly, in most cases, this remains rather superficial as some sort of introductory course. The road to the applications, or the specific requirements of such applications, are taught more as an exception than as best practice. And, any exceptions to this are mainly in the area of game design, understating other possibilities.

*Table 2: Summary of subjects taught in various courses on VR*

| Subjects | | | Courses | |
|---|---|---|---|---|
| | | | Number | Percentage |
| Core | Modelling | | 54 | 49% |
| | | Geometry | 47 | 42% |
| | | Aural/Haptic | 11 | 10% |
| | | Simulation | 13 | 12% |
| | | Virtual Human | 4 | 4% |
| | Psychology | | 21 | 19% |
| | | Human factors | 15 | 14% |
| | | VR Experience | 6 | 5% |
| | | Measurement | 2 | 2% |
| | Technology | | 75 | 68% |
| | | Software | 64 | 58% |
| | | Hardware | 26 | 23% |
| | | Issues | 6 | 5% |
| | Design | | 30 | 27% |
| | | Development | 4 | 4% |
| | | Virtual Art | 4 | 4% |
| | | Interaction | 28 | 25% |
| Related | Applications | | 41 | 37% |
| | Context | | 58 | 52% |
| | | About VR | 54 | 49% |
| | | Culture of VR | 4 | 4% |
| | | Philosophy of VR | 0 | 0% |
| | Simulation | | 9 | 8% |

*Note: Based on 111 courses*

*Textbox 3. Content of course "Creating Virtual Reality" of the University of Bradford.*

1. The basics software tools of Virtual Reality Modelling Languages.
2. Virtual Reality development on the World Wide Web.
3. Virtual World basics.
4. Virtual object building.
5. Light, sound and complex shapes.
6. Animation and complex interactions.
7. Scripting within animation.
8. Colours normals and textures.
9. Publishing virtual worlds.

A few examples of courses are given in Textbox 3 and Textbox 4. These are two courses illustrative of how VR currently is taught. These examples clearly show how a selection have been made of the different subjects of VR, leaving out other important subjects. The course "Creating Virtual Reality" University of Bradford is mainly focused on software (technology), animation (modelling) and interaction design (designing VR). The course "Virtual Environments" of the University College of London takes a broader perspective, also teaching on hardware (technology), VR experience (psychology) and VR applications (context). Both courses view VR mainly from a graphical point of view and remain rather superficial on the other subjects, as indicated on the course website of the University College of London: "*the focus on the technical side will be more on the visual aspects of VEs*".

Basically, two types of courses can be differentiated, stemming from different backgrounds. Most courses stem from specific disciplines (e.g., computer science, graphics) that focus in depth on one of the subjects or mostly an aspect of a subject (e.g., the programming of 3D graphics). Some courses stem from a domain (e.g., industrial design), and describe how the technique of VR can enhance the practice of that domain (e.g., how physical mock-ups can be reduced through the use of VR).

The review and background of the courses lead to two remarkable perceptions, accompanied by two important problems. The first being that most courses only attend to those matters in detail that belong to their own discipline. The consequence of this narrow view on VR is that several core subjects are left out or at most viewed only on a superficial level. The second perception concerns those courses which do

*Textbox 4. Content of course "Virtual Environments" of the University College of London*

| | |
|---|---|
| Introduction | Virtual Environment Technology<br>Requirements<br>Applications |
| Interaction | 3D Interaction tasks<br>Tracking<br>Input devices<br>System affordances<br>3D Widgets |
| Presence | Immersion and presence<br>Meaning and utility of presence<br>Measuring presence |
| Displays | 3D and Stereo Viewing<br>HMDs, CAVEs and desks<br>Graphics Architectures |
| Programming Virtual Environments | Programming models<br>Simulation and animation<br>Programming for distribution ves |
| Devices | Haptic devices<br>Sound simulation<br>Augmented reality |

view VR in more breadth. These courses give an integrated view of the different subjects, but are typically oriented to an application in their own domain and remain at best superficial about the other subjects. This results in lack of integration between related subjects and core subjects.

Confirming these perceptions is the current availability of Bachelor and Master programmes in VR. These are very rare. A few exceptions do exist though, such as the master in “Vision, Imaging and Virtual Environments” at the University College of London[3] (see Textbox 5) or the “Mastere Specialise Simulation Et Realite Virtuelle” (Specialised Master of Simulation and Virtual Reality) and the “Master Recherche en Immersion Virtuelle” (Research Master in Immersive Virtual Reality) at the Institute Image[4]. Still, by primarily focussing on the technical VR subjects, these masters confirm the findings on course level.

Summarising the findings on current education on VR, two key problems exists: several core subjects do not receive enough attention and an integration of all VR subjects, core and related, is lacking. These problems can account for current difficulties in utilizing the full potential of VR. This can easily be imagined considering some of the topics described at the elaborated views, chapter 2.3. As an example of the importance of all core subjects, the believability of autonomous virtual humans should be considered compared to the realism of their appearance. As illustrated by the believability of Bugs Bunny, the aim for as realistic as possible looking virtual humans seems not beneficial to their believability. For an example on the problem of integration, one only has to connect this question to the usability (i.e., effectiveness) of using virtual tutors in an educational VR system.

## 3.2. Recommendations

Based on the review of current VR education, several recommendations can be formulated to improve the education on VR. The first being the incorporation of all core VR subjects in an educational VR programme, with a high level of detail for all core VR subjects and concern for the integration of the subjects. The second being the availability of related subjects, such that as much as possible related courses should be optional to support various specialisations.

One of the biggest problems facing the implementation of

*Textbox 5. Contents of the MSc programme “Vision, Imaging and Virtual Environments” of the University College of London.*

***Core Components***

- Mathematical Methods, Algorithmics, and Implementations (MMAI)
- Image Processing (IP)
- Graphical Modelling and Visualisation (GMV)
- Mathematical Programming and Research Methods (MPRM)

**Optional Advanced Courses (choice of three)**

- Pattern Recognition and Machine Vision (PRMV)
- n-Dimensional Signal Processing (nDSP)
- Virtual Environments (VE)
- Multimedia Systems (MS)
- Advanced Rendering and Animation (ARA)
- Medical Scientific Computing (MSC)
- Information Theory (IT)
- Advanced Methods in Machine Learning

[3] http://www.ucl.ac.uk/

[4] http://www.ai.cluny.ensam.fr/

these recommendations is the sheer amount of subjects such an educational programme needs to incorporate. Several other multi-disciplinary programmes, such as Human-Media Interaction[5], Artificial Intelligence[6] and Industrial Design Engineering[7], face the same problem. These programmes have solved this problem using two methods. First, the level of detail on several of the subjects is flexible, though at least reasonable. Optional courses are available for whom who seeks to raise this level of detail. And second, in the cases of Artificial Intelligence and Industrial Design Engineering, the programmes utilize the full Bachelor-Master structure to ensure a sufficient level of detail for all core subjects. These methods can be translated to the education on VR, enhancing the first recommendation and adding a third one, being the use of a combined Bachelor-Master programme to be able to teach all core and several related VR subjects.

Thus, summarising the educational recommendations:

1. All core VR subjects should be incorporated in an educational VR programme, with a flexible though sufficient level of detail.
    a. Optional courses should be available for whom who wishes to raise this level of detail.
    b. Concern should be taken for the integration of the subjects.
2. As much as possible related courses should be available, such that various specialisations (e.g., on various applications or simulations) are possible.
3. A combined Bachelor-Master programme should be used to cope with the amount of subjects.

An example of an educational programme is given in Textbox 6. This is adapted from an existing MSc programme which focuses primarily on graphics and games technology. Using the recommendations, several practical changes can be given which give a valuable insight in setting up a general VR educational programme.

The first recommendation considers the teaching of all core subjects. When comparing this specialised programme to the identified subjects of VR, several core subjects are less well represented. These are primarily psychological and design subjects, or subjects related to other devices supporting other modalities than visual and auditory. In Textbox 6 three examples have been added of course modules covering parts of the less presented subjects. When a high level of detail is to be received, these course modules can get quite substantial.

The first sub-recommendation (1a) copes with this level of detail, by stating the importance of optional courses to enhance this level of detail. An example of such an optional course might consider the creative aspects of creating a VE, or the modelling of human behaviour. The second sub-recommendation (1b), considering the integration of the various subjects, is addressed explicitly by the added course Designing VR Systems. Although the importance of the uses of the various subjects is pointed out by most of the course modules.

[5] http://hmi.ewi.utwente.nl/

[6] http://www.csail.mit.edu/

[7] http://www.coa.gatech.edu/id/

The second recommendation states the importance of related courses, and the possibility to specialise in their subjects. In the illustrated MSc programme this hasn't been incorporated, due to the focus on the gaming application. Still, in a more general VR programme, the possibilities should exists to specialise in a certain use of VR (e.g., for educational or design uses) or certain simulation requirements.

The third recommendation states a combined Bachelor-Master programme is needed to cope with the amount of subjects. This need becomes obvious when adding a sufficient level of detail to all course modules and when considering the prerequisite knowledge required for these course modules. To name a few: electromechanics, signal-theory, computer architectures, programming skills, interaction design and artificial intelligence.

*Textbox 6. Course modules of the MSc program "Virtual Reality and Games Technology" of the University of Salford, including added course modules.*

**Virtual Environment Technology**: Introduction to the Human, software and hardware issues of creating compelling interactive 3D environments.

**3D Development Techniques**: Advanced programming and mathematical skills required to develop 3D systems.

**3D Graphics and simulation**: 3D graphics system programming, both for real-time 3D rendering and 3D simulation (behavioural) modelling.

**Immersive Virtual Environments**: Developing 3D systems that offer enhanced user interaction through the use of the centre's display facilities and other specialized equipment.

**Populated Virtual Environments**: Populated virtual environments are widely used in computer games and are now being taken up in many industrial applications. They are places to interact with people in a natural way regardless of their physical locality or even lack of existence in the real world.

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**Innovative I/O Devices**: The technical properties, uses and psychological effects of less usual I/O devices, such as haptical devices.

**Human Factors and Cyberpsychology**: The human (dis)abilities in their use of VR systems, combined with the experience of the use and empirical methods to measure human factors.

**Designing VR Systems**: Guidelines and methods to make the best use of all possibilities VR offers. Using a joint project the integration of the various subjects is enhanced.

This review of how these recommendations can be acted out to create a general educational programme on VR is purely illustrative, and as such incomplete. A more detailed educational programme is beyond the scope of this deliverable, and can be expected in future deliverables.

Acting out the recommendations will have consequences on several areas. Namely, acting out these recommendations will have influence on the education on VR, the science of VR and VR as a technology. First, the implications for education are directly related to the recommendations, as in the creation of new Bachelor-Master programmes on VR. Furthermore, these programmes can only be taught at universities already teaching the various VR subjects in order to enable a sufficient level of detail on each subject without greatly increasing cost, creating a few top-notch universities in VR.

Second, the recommendations involve envisioned improvements for VR as a science. Due to the focus on the integration of the different subjects, new scientific improvements become possible. And, due to the generating of new VR specialist, more scientific effort can be expected on VR.

Last, extensive education can enable living VR up to its full potential.

# 4. Conclusion

This paper described what subjects constitute VR and how these subjects are incorporated in current education on VR. Four core subjects have been determined: modelling, psychology, technology and designing VR. Each subject comprises of several topics, going on to various levels of detail. Three related subjects have been defined: application requirements, context and simulation. The depth and multidisciplinary character of VR have been illustrated with various specific topics on VR. The review on how these subjects are taught in current education on VR identified two problems. As first, the focus in current education is very much in depth on a certain subject. As second, little attention is paid to the integration of the different subjects. These problems can account for a lack of overview and only superficial education of some core VR subjects.

Three recommendations have been formed according to this review of current VR education:

1. All core VR subjects should be incorporated in an educational VR programme, with a flexible though sufficient level of detail.
2. As much as possible related courses should be available, such that various specialisations are possible.
3. A combined Bachelor-Master programme should be used to cope with the amount of subjects.

Acting out these recommendations is expected to have positive impact on education on VR, science of VR and VR as a technology. Maybe, finally, reaching the original dream of VR as formulated by Ivan Sutherland in 1965: To let the "*virtual world look real, sound real, move and respond to interaction in real time, and even feel real*" (Brooks, 1999, p.17).

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# Appendix A: Overview of VR courses in Europe

This appendix provides the updated and extended information as was provided in the INTUITION Internal Report on Training and Education Courses in VR/VE (2004) of Mirabelle D'Cruz and Harshada Patel (deliverable D3.1_1). All contacts of the courses depicted in D3.1_1 were contacted through e-mail. The feedback received was used to update the information of D3.1_1. The courses from providers that did not respond were left unchanged.

Three levels of courses are distinguished: undergraduate, postgraduate, doctoral courses, professional training courses. Of each course the following information is provided, if available: country, name of course, where the course is delivered, web address, details of course contact, and partners with experience. This information can be found in Table A1-A4, as provided in this section. Section 2 provides some brief conclusions on VR courses in Europe in general and denotes the differences between this appendix and the original deliverable of D'Cruz and Patel (2004).

# 1. Undergraduate Courses

A list of undergraduate courses is shown in Table 1 below. There are 115 courses listed. A breakdown of their location and in order of the number of courses available is as follows:

- UK (38 courses)
- Germany (15 courses)
- Austria (7 courses)
- Denmark (7 courses)
- Sweden (7 courses)
- Czech Republic (6 courses)
- Poland (6 courses)
- France (5 courses)
- Spain (5 courses)
- The Netherlands (4 courses)
- Switzerland (4 courses)
- Finland (3 courses)
- Greece (3 courses)
- Ireland (1 course)
- Italy (1 course)
- Norway (1 course)
- Portugal (1 course)
- Turkey (1 course)

Based on responses to the Integrated Questionnaire and calls for information 11 INTUITION partners (CNRS, EPFL, ETH, HUT, ICCS, INRIA, PERCRO, UCY, UNott, UoS, UTwente) have experience of 17 of these courses in either delivering or attending them.

.

| Country | Name of course | Where course is delivered | Web address | Details of course contact | Partners with experience |
|---|---|---|---|---|---|
| Austria | Virtual Reality 1 | FH Joanneum Gesellschaft mbH | http://informations-design.fh-joanneum.at/lehre/LehrveranstaltungenDetail.asp?lan=EN&slvaid=7468 | Grabner Markus – grabner@icg.tu-graz.ac.at | |
| Austria | Virtual Reality 2 | FH Joanneum Gesellschaft mbH | http://informations-design.fh-joanneum.at/lehre/LehrveranstaltungenDetail.asp?lan=EN&slvaid=8017 | Grabner Markus - grabner@icg.tu-graz.ac.at | |
| Austria | Architektur Algorithmen/Real Virtuality | Vienna University of Technology | http://tuwis.tuwien.ac.at/zope/tpp/lv/lva_html?num=252041&sem=2006W | Florian Ledermann - ledermann@ims.tuwien.ac.at | |
| Austria | Virtual and Augmented Reality: Geräte und Methoden | Vienna University of Technology | http://tuwis.tuwien.ac.at/zope/tpp/lv/lva_html?num=186156&sem=2007S | Florian Ledermann - ledermann@ims.tuwien.ac.at | |
| Austria | Virtual Reality (LVA:188370) | Vienna University of Technology | http://www.ims.tuwien.ac.at/teaching_detail.php?ims_id=186057 | Florian Ledermann - ledermann@ims.tuwien.ac.at | |
| Austria | Virtual Reality (LVA:188369) | Vienna University of Technology | http://www.ims.tuwien.ac.at/teaching_detail.php?ims_id=188369 | Hannes Kaufmann - kaufmann@ims.tuwien.ac.at | |
| Austria | Special Topics in Virtual Reality (LVA:186088) | Vienna University of Technology | http://www.cg.tuwien.ac.at/courses/SpecialTopicsVR/VU.html | Anton Fuhrmann – fuhrmann@vrvis.at | |
| Czech Republic | Computer vision and Virtual Reality | Czech Technical University | http://web.cvut.cz/en/int/prospectus/stop05/f300/subjXE33PVR.html | Petr Zacha – zachape@vc.cvut.cz | |
| Czech Republic | Virtual Reality (PGR012) | Czech Technical University | http://www.cgg.cvut.cz/~zara/PGR012/ | Doc. Ing. Jiří Žára, CSc. – zara@fel.cvut.cz | |
| Czech Republic | Programming (PA 111VR) | Czech Technical University | http://www.cgg.cvut.cz/~zara/PA111/ | Doc. Ing. Jiří Žára, CSc. – zara@fel.cvut.cz | |

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|---|---|---|---|---|---|
| Czech Republic | Virtual Reality (P36VR) | Czech Technical University | http://www.cgg.cvut.cz/~zara/P36VR/ | Doc. Ing. Jiří Žára, CSc. – zara@fel.cvut.cz | |
| Czech Republic | Multimedia Systems (36 MUS) | Czech Technical University | http://cs.felk.cvut.cz/webis/en/courses/36MUS.html | http://cs.felk.cvut.cz/webis | |
| Czech Republic | Virtual Reality and VRML Language (CT04) | Czech Technical University | http://www.cgg.cvut.cz/~zara/ATHENS/ | Doc. Ing. Jiří Žára, CSc. – zara@fel.cvut.cz | |
| Denmark | Virtual Reality | Aalborg University | http://www.cvmt.auc.dk/~cbm/teaching/vr/vr.html | cbm@cvmt.auc.dk | |
| Denmark | Auralisation and Virtual Reality Sound (ACO9-4) | Aalborg University | http://esn.auc.dk/kurser/en/ACO9_4.pdf | http://esn.auc.dk | |
| Denmark | Virtual Reality (FP9-8) | Aalborg University | http://esn.aau.dk/kurser/en/FP9_8.pdf | http://esn.auc.dk | |
| Denmark | Virtual Reality | Aarhus University | http://www.nat.au.dk/default.asp?la=dk&id=4265&aar=2001 | Peter Møller-Nielsen - pmn@daimi.au.dk | |
| Denmark | 3D Graphical Systems and Virtual Reality | Aarhus University | http://wiki.daimi.au.dk/cgf04/cgf04.wiki | Peter Møller-Nielsen - pmn@daimi.au.dk | |
| Denmark | Virtual Reality Systems (02563) | Technical University of Denmark | http://www.kurser.dtu.dk/presentation/presentation.asp?menulanguage=en-gb&coursecode=02563-3&version=full | Niels Jørgen Christensen - njc@imm.dtu.dk | |
| Denmark | Virtual Reality Systems (04353) | Technical University of Denmark | http://www.imm.dtu.dk/courses/04353/04353kur.pdf | http://www.imm.dtu.dk/English.aspx | |
| Finland | Virtual Reality (T-111.400) | Helsinki University of Technology | http://www.tml.hut.fi/Studies/T-111.400/ | Tapio.Lokki – Tapio.Lokki@hut.fi Lauri.Savioja – Lauri.Savioja@hut.fi | HUT |
| Finland | Virtual Reality (81524S) | University of Oulu | http://www.tol.oulu.fi/~tmannine/vrt/ | http://www.tol.oulu.fi | |
| Finland | Special Course on Networked Virtual | University of Turku | http://staff.cs.utu.fi/kurssit/scnve/spring_2002/ | Timo Kaukoranta – | |

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|---|---|---|---|---|---|
| | Environments | | | Timo.Kaukoranta@cs.utu.fi | |
| France | Scene generation in Virtual Reality (S1833) | Ecole de Mine de Paris | http://www.ensmp.fr/Fr/Formation/2emeCycle/IngCivil/Enseignement/Ens-S1833.html | http://www.ensmp.fr | |
| France | Introduction to Virtual Reality | European Summer University<br>ENSTA (Ecole Nationale Supérieure de Techniques Avancées) | http://www.paristech.org/anglais/esu05_e.html | esu@paristech.org | |
| France | Image Synthesis and Virtual Reality | Institut Eurécom | http://www.eurecom.fr/Curriculum/Teaching/multimediacourses.html#Top | http://www.eurecom.fr | |
| France | Virtual Reality<br>(IF-51RV) | Institut Nationaux des Sciences Appliquees Rennes | http://www.insa-rennes.fr/d-info/gb/5/if-51rva.html | Bruno Arnaldi –<br>Bruno.Arnaldi@insa-rennes.fr | INRIA |
| France | Fundamentals of Virtual Reality and Advanced Interfaces | Université Paris Sud | http://master.lri.fr/recherche/intranet/current/cours/affiche_cours.php?wsl_dir_project=/users/master/master/WWW/recherche/intranet/current&cours=31 | Patrick Bourdot – Patrick.bourdot@limsi.fr | CNRS |
| Germany | VR-Technologie | Fachhochschule Furtwangen (professional education) | http://vr.iao.fhg.de/fhf/index.de.php?link=fhf/index&lang=de&mark=main:lehre:vorlesungFHF | tim.gleue@iao.fhg.de | |
| Germany | Visualization and Virtual Reality | Darmstadt University of Technology | http://www.tu-darmstadt.de/vvss98/comments/20.133.en.html | W. Loring –<br>loring@pvw.tu-darmstadt.de<br>M. Notzon -<br>notzon@pvw.tu-darmstadt.de | |
| Germany | Virtual Reality and Information Visualization | Darmstadt University of Technology | http://www.tu-darmstadt.de/vvws03-04/comments/20.124.en.tud | Hemmje, Jäschke, Wang –<br>http://www.tu-darmstadt.de | |
| Germany | Virtual Reality in industrial applications (VDT2005) | Fraunhofer Institute for Factory Operation and Automation | http://www.ifsl-schenk.de/vorlesung/vr_in_industriellen_anwendungen.htm | Eberhard Blümel -<br>eberhard.bluemel@iff.fraunhofer.de | |

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|---|---|---|---|---|---|
| Germany | Virtual Reality | RWTH Aachen University | http://www.rz.rwth-aachen.de/vr/teaching/lectures/lectures.php | Torsten Kuhlen – kuhlen@rz.rwth-aachen.de | |
| Germany | Man-Machine Interfaces | Technical University of Hamburg-Harburg (TUHH) | http://www.tu-harburg.de/et6/lectures/man-machine.html | Ulrich Killat – killat@tuhh.de | |
| Germany | Virtual and Augmented Reality | Universität Koblenz-Landau | http://www.uni-koblenz.de/~cg/veranst/ss03/vrar.html | Stefan Müller – cg@uni-koblenz.de | |
| Germany | Fragments and the Virtual Environments in Experience Areas (AR07 Project2) | University of Applied Science Konstanz (FH-Konstanz) | http://www2.fh-konstanz.de/studium/fachb/wwwag/SS2003/Fragments.htm | Enquiries – kontakt@fh-konstanz.de | |
| Germany | Advanced virtual environments (WS2003/2004) | University of Applied Sciences Bonn-Rhein-Sieg | http://www2.inf.fh-bonn-rhein-sieg.de/~ahinke2m/ | André Hinkenjann - Andre.Hinkenjann@fh-bonn-rhein-sieg.de | |
| Germany | Virtual Reality | University of Applied Sciences Bremerhaven | http://www1.hs-bremerhaven.de/umland/lv/vr-ar/index.html | Claudia Krieten - ckrieten@hs-bremerhaven.de | |
| Germany | Interactive Computer Graphics | University of Erlangen-Nuremberg | http://www9.informatik.uni-erlangen.de/Teaching/SS2003/InCG | Marc Stamminger – Marc.Stamminger@informatik.uni-erlangen.de | |
| Germany | Virtual Reality | University of Siegen | http://pi.informatik.uni-siegen.de/akkred/module/CGM/VR.html | Roswitha Eifler – eifler@informatik.uni-siegen.de | |
| Germany | Graphical-Interactive Systems | University of Stuttgart | http://www.vis.uni-stuttgart.de/eng/teaching/lecture/ws03/gis/ | Daniel Weiskopf – weiskopf@informatik.uni-stuttgart.de | |
| Germany | Computer Graphics | University of Tuebingen | http://www.gris.uni-tuebingen.de/ | Constanze Christ – sekr@gris.uni-tuebingen.de | |
| Germany | Virtual Environments - Technology and Systems (SS200) | University of Weimar | http://xyz.scc.uni-weimar.de/medien/vr/lectures/SS2003/index_en.ht | Ingrid Eismann Tel.: +49(0)36 43/58 23 58 | |
| Greece | Virtual Reality | Aristotle University of Thessaloniki | http://www.csd.auth.gr/personnel/info.en.php?id=nikolaid | Nikolaidis Nikolaos – nikolaid@zeus.csd.auth.gr | |

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| Greece | Virtual Reality COMP 430 | Ithaca College | http://www.ithaca.edu/faculty/sstansfield/cs430_syllabus.html | Professor Sharon Stansfield - sstansfield@ithaca.edu | |
| Greece | Educational Virtual Environments | University of Ioannina | http://www.primary.edu.uoi.gr/earth_lab/index_en.htm | Pegka Sofia – spegka@cc.uoi.gr | |
| Ireland | Computer Graphics and Virtual Reality (4ICT10) | Trinity College | http://www.cs.tcd.ie/courses/baict/bass/4ict10/ | Dr. Ann M. McNamara - ann.mcnamara@tcd.ie | |
| Italy | Realtà Virtuale | Computer Science Faculty, Pisa | http://percro.sssup.it/~marcello/didattica/ | bergamasco@sssup.it marcello@sssup.it | PERCRO |
| Norway | VRML in Chemistry | Norwegian University of Science and Technology | http://pcf1.chembio.ntnu.no/~bka/div/vrml/moldyn.htm | Bjorn Alsberg – bjorn.alsberg@phys.chem.ntnu.no | |
| Poland | Data visualization in VRML | Gdansk University of Technology | http://www.eti.pg.gda.pl/katedry/ksg/dydaktyka/Wizualizacja_danych_w_jezyku_VRML/ | marmo@pg.gda.pl | |
| Poland | Multimedia interactive systems | Gdansk University of Technology | http://www.eti.pg.gda.pl/katedry/kiw/dydaktyka/Multimedialne_Systemy_Interaktywne/ | szwoch@eti.pg.gda.pl jandac@eti.pg.gda.pl jacekl@eti.pg.gda.pl | |
| Poland | Virtual Reality | Gdansk University of Technology | http://www.eti.pg.gda.pl/katedry/kiw/dydaktyka/Rzeczywistosc_Wirtualna/ | jacekl@eti.pg.gda.pl szwoch@eti.pg.gda.pl | |
| Poland | Interactive graphics and 3D visualization | Gdansk University of Technology | http://www.eti.pg.gda.pl/katedry/kib/pracownicy/Agnieszka.Janczulewicz/giw3d.html | jacekl@eti.pg.gda.pl szwoch@eti.pg.gda.pl | |
| Poland | 3D Modelling and Data Visualization | Poznan University of Technology | http://www.fcm.put.poznan.pl/platon/files/opisyPrzedmiotow/in_zmu/ge_z/2/p001071622001071767.rtf | Marta.Kasprzak@cs.put.poznan.pl | |
| Poland | Advanced Graphics | Wroclaw University of Technology | http://www.wiz.pwr.wroc.pl/popup_course.asp?code=INZ3511&year=2004&lang=pl | Jerzy.Sas@pwr.wroc.pl | |
| Portugal | Computer Graphics and Virtual Environments | University of Minho | http://www.uminho.pt/ModuleLeft.aspx?mdl=~/Modules/ECTS_PG/PortalModules/Plano.ascx&c=ME30&mid=271&lang=en-S&pageid=190&tabid=18 | José Bernardo Santos Monteiro Vieira Barros – jbb@di.uminho.pt | |

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| Spain | Multimedia Systems | Polytechnic University of Madrid | http://www.upm.es | Juan Manuel Meneses Chaus juan.meneses@upm.es | |
| Spain | Virtual Reality and Animation | Universidad Rey Juan Carlos | http://dac.escet.urjc.es/docencia/RVA/ | info@urjc.es | |
| Spain | VR and Animation | Universidad Rey Juan Carlos | http://www.urjc.es/cat/catalogo.pdf | cat@escet.urjc.es | |
| Spain | Virtual and Augmented Reality | University of Pais Vasco | http://scsx01.sc.ehu.es/siwebso/Alumnos/G_docente_0405/Asignaturas_ofertadas/Temarios0405/II_P45_16332.html#ingl | titulaciones@lg.ehu.es | |
| Spain | Human-Machine interaction | University of Zaragoza | http://giga.cps.unizar.es/English/Edoc-d-hommaq.html | seron@posta.unizar.es | |
| Sweden | Programming 3D Graphics and Virtual Reality | Linkopings University | http://www.ida.liu.se/~vaden/gl/ | Vadim Engelson – vaden@ida.liu.se | |
| Sweden | Virtual Reality Technologies and Programming (TNM053) | Linkopings University | http://www.itn.liu.se/~matco/TNM053/ | Matt Cooper – matco@itn.liu.se | |
| Sweden | Virtual Environments (SMM003) | Lluleå University of Technology | http://www.luth.se/publ/stuka/2001/3210/KSMM003.en.htm | International.Office@adm.luth.se | |
| Sweden | Using Virtual Reality – new possibilities in various applications (TNM-140) | Lund Institute of Technology | http://www.reflex.lth.se/courses/TNM140/LectureNotes/VRIntro_files/frame.htm | Roy Davies – roy.c.davies@ieee.org | |
| Sweden | Introduction to Virtual Reality (CT3430) | Malardalen University / IDP | http://www.idt.mdh.se/kurser/ct3430 | Thomas Larsson – thomas.larsson@mdh.se | |
| Sweden | Virtual Reality (TDBD 12) | Umeå University | http://www.cs.umu.se/kurser/TDBD12 | Per Lindstrom – perl@cs.umu.se | |
| Sweden | Presence in Virtual Environments | Umeå University | http://www.info.umu.se/utbkat/KursEng.asp?kurskod=INFD12&termin= | international.admissions@adm.umu.se | |
| Switzerland | Virtual Reality (SPVR Term Project) | Berne University of Applied Sciences | http://www.sws.bfh.ch/studienbetrieb/studp/index.xhtml | Francine Ackermann – | |

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|---|---|---|---|---|---|
| | | | | Francine.ackermann@bfh.ch | |
| Switzerland | Virtual Reality in Medicine<br>(227-0279) | Polytechnic Federal Institute of Technology (ETH) | http://control.ee.ethz.ch/~ifareg/VR_Course/VRinMedicine.msql | Robert Riener –<br>Robert.riener@control.ee.ethz.ch<br>Matthias Harders –<br>Matthias.harders@vision.ee.ethz.ch | ETH |
| Switzerland | Virtual Reality and Multimodal Interaction | Polytechnic Institute of Lausanne (EPFL) | http://ic2.epfl.ch/postgr/descr2002/DT2002.html | Daniel Thalmann –<br>Daniel.thalmann@epfl.ch | EPFL |
| Switzerland | Advanced virtual reality systems and telepresence<br>(IC-04) | Polytechnic Institute of Lausanne (EPFL) | http://lthipc5.epfl.ch/cc/course.php?IC-04 | Daniel Thalmann –<br>Daniel.thalmann@epfl.ch | EPFL |
| The Netherlands | Introduction to virtual reality<br>(IN3031) | Delft University of Technology | http://is.twi.tudelft.nl/ontwerpen/courses/in3010tu.html | Jan Dietz –<br>J.L.G.Dietz@is.twi.tudelft.nl | |
| The Netherlands | 3D Computer Graphics and Virtual Reality<br>(IN4006) | Delft University of Technology | http://www.cg.its.tudelft.nl/index.php?id=406 | F.W. Jansen –<br>F.W.Jansen@ewi.tudelft.nl | |
| The Netherlands | Scientific Visualization and Virtual Reality | University of Amsterdam | http://www.science.uva.nl/research/scs/edu/scivis/ | Jaap A. Kaandorp –<br>jaapk at science.uva.nl | |
| The Netherlands | Design with virtual reality | University of Twente | http://www.utwente.nl | D.Lutters@utwente.nl | UTwente |
| The Netherlands | Intelligent multimedia technology | Vrije Universiteit Amsterdam | http://www.cs.vu.nl/~eliens/imt/ | eliens@cs.vu.nl | |
| Turkey | Computerized Modeling and Simulation<br>(MECH 534) | Koc University | http://network.ku.edu.tr/~cbasdogan/courses/Computer-Based/syllabus534.htm | Cagatay Basdogan –<br>cbasdogan@ku.edu.tr | |

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| UK | 3D Graphics, Virtual Reality & Animation (EE3105) | Brunel University | http://www.brunel.ac.uk/admin/registry/module/curr/module_detail_si/EE3105.shtml | Admissions@brunel.ac.uk | |
| UK | Virtual Reality<br>(COP 381) | Loughborough University | http://www.lboro.ac.uk | Roy Kalawsky –<br>r.s.kalawsky@lboro.ac.uk | |
| UK | Virtual Environments (CO42001) | Napier University | http://www.soc.napier.ac.uk/module/op/onemodule/moduleid/CO42001/ | Leanne McNab –<br>l.mcnab@napier.ac.uk | |
| UK | Virtual Reality | Sheffield Hallam University | http://www2.shu.ac.uk/prospectus/op_uglookup1.cfm?id_num=CMS011&CurrTab=4 | aces-info@shu.ac.uk | |
| UK | Virtual Reality: Applications and Implementation (CM316) | Sheffield Hallam University | http://www2.shu.ac.uk/prospectus/op_uglookup1.cfm?id_num=CMS011&CurrTab=4 | aces-info@shu.ac.uk | |
| UK | Virtual Reality<br>(GG46) | Staffordshire University | http://www.staffs.ac.uk/courses/undergrad/mediaandentertainmenttechnology/tcm1984864.php | Ann Grainger –<br>fcet@staffs.ac.uk | |
| UK | Virtual Environments (4076/VE) | University College London | http://www.cs.ucl.ac.uk/teaching/syllabus/ug/4c76.htm | Anthony Steed –<br>A.Steed@cs.ucl.ac.uk | UCY, ICCS |
| UK | Computer Graphics and Virtual Environments | University College London | http://www.cs.ucl.ac.uk/staff/A.Steed/book_tmp/CGVE/ | Mel Slater –<br>m.slater@cs.ucl.ac.uk | ICCS |
| UK | Computer Games Technology<br>(G470 BSc/CGT) | University of Abertay Dundee | http://www.abertay.ac.uk/Courses/CDetails.cfm?RID=2&CID=185 | sro@abertay.ac.uk | |
| UK | Future Interactive Systems<br>(EE3K1) | University of Birmingham | http://www.eee.bham.ac.uk/eece/ug/eee_structure.aspx | uga-eece@bham.ac.uk | |
| UK | Virtual Reality<br>(06-02645) | University of Birmingham | http://www.cs.bham.ac.uk/resources/modules/2003/02645.html | L Jankovic –<br>L.Jankovic@cs.bham.ac.uk | |
| UK | BSc Cybernetics and Virtual Worlds | University of Bradford | http://www.inf.brad.ac.uk/courses/ug/course.php?id=1&d=cvw&type=a-z | eng-enquiries@bradford.ac.uk | |

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|---|---|---|---|---|---|
| UK | BSc (Hons) in Virtual Design & Innovation | University of Bradford | http://www.eng.brad.ac.uk/UG_studies/design/?page=vdi | eng-enquiries@bradford.ac.uk | |
| UK | Virtual Reality Technology (COMP1048) | University of Greenwich | http://cms1.gre.ac.uk/programmes/cms/coursespecs/COMP1048.doc | Tony Ackroyd – T.Ackroyd@gre.ac.uk | |
| UK | Interactive Environments (COMP 1322 3D) | University of Greenwich | http://cms1.gre.ac.uk/programmes/cms/coursespecs/COMP1322_2004.doc | Tony Ackroyd – T.Ackroyd@gre.ac.uk | |
| UK | Virtual Reality Design | University of Huddersfield | http://www.hud.ac.uk/courses/undergrad/ipp_pages00000218.htm | Derek Hales – d.hales@hud.ac.uk | |
| UK | Virtual Reality Design with Animation | University of Huddersfield | http://www.hud.ac.uk/courses/undergrad/ipp_pages00000553.htm | Derek Hales – d.hales@hud.ac.uk | |
| UK | Advanced Computer Graphics (COMP3650) | University of Leeds | http://www.comp.leeds.ac.uk/royr/gi31/ | Roy Ruddle – royr@comp.leeds.ac.uk | |
| UK | Multimedia and Virtual Reality (CT454) | University of Manchester | http://www.co.umist.ac.uk/hci_design/MMVRteach.htm | Alistair Sutcliffe – a.g.sutcliffe@co.umist.ac.uk | |
| UK | Human-Computer Interaction | University of Nottingham | http://www.nottingham.ac.uk | Sarah Sharples – sarah.sharples@nottingham.ac.uk | UNott |
| UK | User Interface Design (G52UID) | University of Nottingham | http://www.crg.cs.nott.ac.uk/~sdb/uid/ | Steve Benford – sdb@cs.nott.ac.uk | UNott |
| UK | Virtual Reality in Architecture (K1DVRA) | University of Nottingham | http://winster.nottingham.ac.uk/modulecatalogue/asp/main_search.asp | B. Medjdoub – Benachir.medjdoub@nottingham.ac.uk | UNott |
| UK | Multimedia and Virtual Reality (G5CMVR) | University of Nottingham | http://www.cs.nott.ac.uk/Modules/0304/G5CMVR.html | G Hopkins – g.hopkins@cs.nott.ac.uk | UNott |
| UK | CAD and Virtual Reality in Architecture (K1DCVR) | University of Nottingham | http://winster.nottingham.ac.uk/modulecatalogue/asp/main_search.asp | Benachir.medjdoub@nottingham.ac.uk | UNott |

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|---|---|---|---|---|---|
| UK | Computer Animation and Virtual Reality 20<br><br>(U13099) | University of Portsmouth | http://www.tech.port.ac.uk/tud/db/UnivPort/level_3/ANMVR20.htm | Roger.eglin@port.ac.uk | |
| UK | Computer Animation and Virtual Reality<br><br>(U06517C) | University of Portsmouth | http://www.tech.port.ac.uk/tud/db/UnivPort/level_3/ANMVR.htm | Roger.eglin@port.ac.uk | |
| UK | MComp/BSc Artificial Intelligence and Computer Science | University of Sheffield | http://www.shef.ac.uk/dcs/undergrad/courses/compsci-1.html | dept@dcs.shef.ac.uk | |
| UK | Computer Speech and Hearing | University of Sheffield | http://www.shef.ac.uk/dcs/undergrad/courses/compsci-1.html | dept@dcs.shef.ac.uk | |
| UK | HCI and Graphical Interfaces | University of Sheffield | http://www.shef.ac.uk/dcs/undergrad/courses/compsci-1.html | dept@dcs.shef.ac.uk | |
| UK | Computer Games Technology<br><br>(COM360) | University of Sheffield | http://www.shef.ac.uk/dcs/undergrad/courses/compsci-1.html | dept@dcs.shef.ac.uk | |
| UK | 3D Computer Graphics | University of Sheffield | http://www.shef.ac.uk/dcs/undergrad/courses/compsci-1.html | dept@dcs.shef.ac.uk | |
| UK | Virtual Reality Systems<br><br>(H7006) | University of Sussex | http://www.sussex.ac.uk/informatics/H7006.html | M.White@sussex.ac.uk<br><br>K.Mania@sussex.ac.uk | UoS |
| UK | Virtual Environments (920G5) | University of Sussex | http://www.sussex.ac.uk/informatics/920G5.html | M.White@sussex.ac.uk<br><br>K.Mania@sussex.ac.uk | UoS |
| UK | Virtual Reality Product Design (H7025) | University of Sussex | http://www.sussex.ac.uk/engineering/H7025.html | P.R.N.Childs@sussex.ac.uk | UoS |
| UK | Virtual Reality (GG46) | University of Teesside | http://www.tees.ac.uk/prospectus/ft2006/ft2006.cfm | courseinfo@tees.ac.uk. | |
| UK | BSc (Hons) Virtual Reality | University of Wolverhampton | http://courses.wlv.ac.uk/Course.asp?menu=1&id=11811&type=1 | international@wlv.ac.uk | |
| UK | 3D Computer Modelling and Visualisation | University of Wolverhampton | http://courses.wlv.ac.uk/Course.asp?menu=1&id=11570&type=1 | international@wlv.ac.uk | |

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|---|---|---|---|---|---|
| UK | Fundamentals of VR | University of Wolverhampton | http://courses.wlv.ac.uk/Course.asp?menu=1&id=11567&type=1 | international@wlv.ac.uk | |

*Table A1: List of undergraduate courses.*

## 2. Postgraduate courses (Masters and Diplomas)

A list of postgraduate courses is shown in Table 2 below. There are 61 courses listed. A breakdown of their location and in order of the number of courses available is as follows:

- UK (22 courses)
- France (13 courses)
- Germany (10 courses)
- Spain (3 courses)
- Switzerland (3 courses)
- The Netherlands (3 courses)
- Greece (2 courses)
- Finland (2 courses)
- Ireland (1 course)
- Portugal (1 course)
- Romania (1 course)

Based on responses to the Integrated Questionnaire and calls for information 17 INTUITION partners (CNRS, CS, FhG-IAO, MPITuebingen, UTBv, IR-UVEG, UPM, EPFL, HUT, CEA, ENIB, MCS, ICCS, INRIA, UCY, USAL, UoS) have experience of 28 of these courses in either delivering or attending them.

| Country | Name of course | Where course is delivered | Web address | Email details of course contact | Partners with experience |
|---|---|---|---|---|---|
| Finland | Virtual Reality (SGN-5406) | Tampere University of Technology | http://pinkpanther.dmi.tut.fi/vr/ | ismo.rakkolainen@tut.fi | |
| Finland | Virtual Reality (T-111.5400) | Helsinki University of Technology | http://www.tml.tkk.fi/Opinnot/T-111.5400/ | Tapio Lokki – Tapio.Lokki@hut.fi | HUT |
| France | Adapting new mechatronic techniques to | CEA – Centre de Saclay | http://www-instn.cea.fr/html/F_univ_2000/ens3cycl/sac/s | Mohamed Khoudja – | CEA |

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|---|---|---|---|---|---|
| | build a new generation of tactile interfaces | | ac2.pdf | mohamed.khoudja@cea.fr | |
| France | Specialized master in information technology | École Centrale Paris | http://www.it.ecp.fr/pdfs/ecp_ms_it_en.pdf | ddagot@ecp.fr<br>lbruyere@ecp.fr | |
| France | Master in VR | Ecole Nationale d'Ingénieurs de Brest | http://www.enib.fr | contact@enib.fr | ENIB |
| France | ESIEA - VR courses | ESIEA Ouest – Etablissement lavallois | http://www.esiea.fr | accueil@esiea.fr | MCS |
| France | Emerging technologies course | ESME Sudria | http://www.esme.fr/ | contact@esme.fr | MCS |
| France | 3D Interaction and Virtual Reality | INRIA | www.inria.fr | Sabine Coquillart –<br>Sabine.coquillart@inria.fr | ICCS<br>INRIA |
| France | Master in VR | Institut des Sciences et Techniques de l'Ingénieur d'Angers | http ://www.istia.univ-angers.fr | Jacques Berrue –<br>Jacques.berrue@istia.univ-angers.fr | |
| France | Master in VR | Institut Image | http://www.ai.cluny.ensam.fr | Géraldine Roux –<br>Tel. 03 85 90 98 60 | |
| France | Master computer science / multimedia | Labri Domaine Universitaire | http://dept-info.labri.u-bordeaux.fr/~vialard/Master/MM/PIRV.html | vialard@labri.fr | MCS |
| France | Beyond Appearances: Creation of a realistic virtual environment | LIMSI-CNRS | http://www.limsi.fr/venise | Patrick Bourdot –<br>Patrick.Bourdot@limsi.fr<br>Jean-Marc Vezien -<br>Jean-Marc.Vezien@limsi.fr | CNRS |
| France | Master in Simulation and Virtual Reality | Mastère Spécialisé SRV<br>Institut Image – ENSAM | http://www.ai.cluny.ensam.fr/ | roux@cluny.ensam.fr | CS |
| France | Virtual Reality and Mastering of Complex Systems | Université d'Evry Val-d'Essonne | http://univ-evry.fr | fchavand@iie.cnam.fr | CNRS |
| France | Numerical Modelisation and Virtual Reality | University of Angers | http://www.istia.univ-angers.fr/Innovation/masterrev/presentation.p | Henri Samier – | INRIA |

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|---|---|---|---|---|---|
| | | | hp | samier@istia.univ-angers.fr | |
| Germany | Systeme der virtuellen Realität | Bauhaus-Universität Weimar | http://www.uni-weimar.de/medien/VR/index.html | Prof. Dr. Bernd Fröhlich<br>bernd.froehlich@medien.uni-weimar.de | FHG-IAO |
| Germany | Computergraphik | Hochschule der Medien<br>Medieninformatik | http://www.hdm-stuttgart.de/ | Prof. Dr. Jens-Uwe Hahn<br>hahn@hdm-stuttgart.de | FHG-IAO |
| Germany | Virtual Reality – Raum als Interface | Hochschule für Gestaltung Stuttgart<br>Communication Design | http://www.merz-akademie.de | Roland Blach<br>roland.blach@iao.fhg.de | FHG-IAO |
| Germany | Virtual Environments (Virtual Reality) | University of Tuebingen | http://www.gris.uni-tuebingen.de/grisalt/study/lectures/vr2006/index.html | fischer@gris.uni-tuebingen.de | |
| Germany | Multimodal Perception and Action | University of Tuebingen | http://www.uni-tuebingen.de/uni/qvr/05/05-01-1.html | Marc Ernst – marc.erns@tuebingen.mpg.de | MPITuebingen |
| Germany | Virtuelle Realität | RWTH Aachen | http://www.rz.rwth-aachen.de/vr/teaching/lectures/ws04/lectures.php | Torsten Kuhlen<br>kuhlen@rz.rwth-aachen.de | FHG-IAO |
| Germany | Erweiterte Realität | Technische Universität München | http://www.informatik.tu-muenchen.de/index.html | Gudrun Klinker<br>klinker@in.tum.de | FHG-IAO |
| Germany | Virtual Reality Technologies | University of Applied Science | http://www.fh-furtwangen.de | Tim Gleue<br>tim.gleue@iao.fhg.de | FHG-IAO |
| Germany | Virtual Reality Technologies | University of Applied Science | http://www.fh-esslingen.de | Matthias Bues<br>matthias.bues@iao.fhg.de | FHG-IAO |
| Germany | Virtual Environments | University of Applied Sciences Bonn-Rhein-Sieg | http://www2.inf.fh-bonn-rhein-sieg.de/~ahinke2m/ | Prof. Dr. André Hinkenjann<br>andre.hinkenjann@fh-bonn-rhein-sieg.de | FHG-IAO |
| Greece | Virtual Reality – Haptics and Applications to Telerobotics | National Technical University of Athens | http://www.ntua.gr | ktzaf@softlab.ntua.gr | ICCS |
| Greece | Virtual Realities in Education | University of Ioannina | http://www.primary.edu.uoi.gr/earth_lab/index_en.htm | Pegka Sofia – | |

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|---|---|---|---|---|---|
| | | | | spegka@cc.uoi.gr | |
| Ireland | Multimedia technology | University College Cork | http://www.ucc.ie/academic/postgraduate/calendar/masters/science/page04.html | sciencefaculty@ucc.ie | |
| Portugal | Computer Graphics and Virtual Environments | University of Minho | http://www.uminho.pt/ModuleLeft.aspx?mdl=~/Modules/ECTS_PG/PortalModules/Plano.ascx&c=ME30&mid=271&lang=en-S&pageid=190&tabid=18 | José Bernardo Santos Monteiro Vieira Barros – jbb@di.uminho.pt | |
| Romania | Mechatronics and Robotics | University Transylvania of Brasov | http://dpr.unitbv.ro | staretu@unitbv.ro | UTBv |
| Spain | 3D modelling, rendering and animation with LIGHTWAVE | Centro de innovación y servicios para el diseño y la tecnología<br>A Cabana, s/n, 15590, Ferrol | http://www.portalformativo.com/CURSO-DE-MODELADO-3D-RENDERIZADO-Y-ANIMACION-CON-LIGHTWAVE-u_1_2261.html | formacion@cisgalicia.org | |
| Spain | Introduction to Virtual Reality | IR-UVEG installations | http://robotica.uv.es | Marcos.Fernandez@uv.es | IR-UVEG |
| Spain | Intelligent Virtual Environments | Universidad Politécnica de Madrid | http://www.upm.es | angelica@fi.upm.es | UPM |
| Switzerland | Virtual Reality | EPFL | http://www.Vrlab.epfl.ch | Daniel Thalmann – Daniel.thalmann@epfl.ch | EPFL |
| Switzerland | Advanced computer graphics | EPFL | http://ligwww.epfl.ch/teaching/teaching_index.html | Daniel Thalmann – daniel.thalmann@epfl.ch | |
| Switzerland | Interface Design | Fachhochschule Aargau | http://www.fh-aargau.ch | Prof. Mario Doulis – m.doulis@fh-aargau.ch | |
| The Netherlands | Scientific Visualization and<br>Virtual Reality | Universiteit van Amsterdam | http://staff.science.uva.nl/~robbel/ | robbel@science.uva.nl | |
| The Netherlands | Masters in Geometry, Imaging and Virtual Environments | Universiteit Utrecht | http://www.uu.nl/uupublish/homeuu/1main.html | www.qdesk.uu.nl | |

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|---|---|---|---|---|---|
| The Netherlands | Advanced Computer Graphics and Virtual Environments (INACGVE-03) | University of Groningen | http://www.rug.nl/fwn/_shared/coursedescription/informatica/master/informatica_2003_2004_/1/3/inacgve_03?lang=en | vpr@bureau.rug.nl | |
| UK | Interactive multimedia | Heriot-Watt University of Edinburgh | http://www.postgraduate.hw.ac.uk/course/153/ | mscenquiries@mcs.hw.ac.uk | |
| UK | Virtual Reality (CMSSEM012) | Liverpool John Moores University | http://www.cms.livjm.ac.uk/courses/modules/vr.htm | Dave England – d.england@livjm.ac.uk | |
| UK | Virtual Environments | University College London | http://www.cs.ucl.ac.uk/teaching/vive/ | Anthony Steed – A.Steed@cs.ucl.ac.uk | UCY, ICCS |
| UK | VR Studies – Architecture | University College London (UCL) | http://www.bartlett.ucl.ac.uk/graduate/programmes/engd.htm | Corrine Frazzoni – c.frazzoni@ucl.ac.uk | |
| UK | Vision Imaging and Virtual Environments | University College London (UCL) | http://www.cs.ucl.ac.uk/teaching/VIVE | admissions@ucl.ac.uk | |
| UK | Computer Games Technology | University of Abertay Dundee | http://www.abertay.ac.uk/Courses/CDetails.cfm?RID=3&CID=186 | sro@abertay.ac.uk | |
| UK | Virtual Reality (CM50110) | University of Bath | http://www.cs.bath.ac.uk/~pjw/NOTES/110-VR/ | Philip Willis – p.j.willis@bath.ac.uk | |
| UK | Human-Centred Design and Methodologies | University of Birmingham | http://www.eee.bham.ac.uk/eece/pg/msc_hcs.aspx | www.apply.bham.ac.uk | |
| UK | Visualization and Virtual Reality (COMS M0105) | University of Bristol | http://www.cs.bris.ac.uk/Tools/Local/Handbook/course_msc_units.html | Martin Baker – http://www.cs.bris.ac.uk/People/send.jsp?id=139997 | |
| UK | Visualisation and VR for Distributed Systems | University of Durham | http://www.dur.ac.uk/computer.science/ | pg.admissions@durham.ac.uk | |
| UK | Virtual Environments: Technologies and Practice | University of East Anglia | http://www.cmp.uea.ac.uk/web/admissions/msvirt.pdf | R.J. Lapeer – rjal@cmp.uea.ac.uk | |
| UK | Smart Design | University of Huddersfield | http://www.hud.ac.uk/courses/postgrad/ipp_pages00000776.htm | R. Hall – r.hall@hud.ac.uk | |

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|---|---|---|---|---|---|
| UK | Virtual Environments and Visualization | University of Hull | http://www.graphicsmsc.com/ | Helen El-Sharkawy – H.M.El-Sharkawy@hull.ac.uk | |
| UK | Advanced Virtual Environments (CS638) | University of Manchester | http://www.cs.man.ac.uk/Study_subweb/Postgrad/ACS-CS/webpages/syllabus/acs/CS638.html | Gill Lester – glester@cs.manchester.ac.uk | |
| UK | Virtual Environments | University of Salford | http://www.nicve.salford.ac.uk/msc/ | David J. Roberts - D.J.Roberts@salford.ac.uk | USAL |
| UK | Computer Games Technology (COM 360) | University of Sheffield | http://www.dcs.shef.ac.uk/teaching/modules/level3/com3160.html | dept@dcs.shef.ac.uk | |
| UK | Multimedia Applications and Virtual Environments | University of Sussex | http://www.cogs.susx.ac.uk/grad/pages/taught-deg/msc-subs/msc-mave.html | Ian Wakeman – ianw@sussex.ac.uk | |
| UK | Virtual Reality Systems | University of Sussex | http://www.sussex.ac.uk/informatics/H7006.html | Dr Martin White - M.White@sussex.ac.uk<br>Dr Katerina Mania - K.Mania@sussex.ac.uk | UoS |
| UK | Virtual Instrumentation and Environments (UFMEEB-15-M) | University of the West of England | http://www.uwe.ac.uk/cems/research/groups/mvl/virtualr.html | Melvyn.Smith@uwe.ac.uk | |
| UK | Advanced Visualization Virtual Environments and Computer Animation | University of Wales, Bangor | http://www.informatics.bangor.ac.uk/public/prospectus/pgrad/msc_avveca.shtml | Nigel W. John – pg-admissions@informatics.bangor.ac.uk | |
| UK | Virtual Environments and Human Perception (ICP4133) | University of Wales, Bangor | http://www.hpv.informatics.bangor.ac.uk/msc.html | Nigel W. John – pg-admissions@informatics.bangor.ac.uk | |
| UK | CAD and construction | University of Wolverhampton | http://asp2.wlv.ac.uk/sebe/Courses/courses.asp?SecID=2&ID=55 | b.quick@wlv.ac.uk | |

*Table A2: List of Postgraduate courses.*

# 3. Doctoral programmes

A list of doctoral programmes is shown in Table 3 below. There are 18 programmes listed. A breakdown of their location and in order of the number of courses available is as follows:

- Spain (7 courses)
- France (4 courses)
- Switzerland (3 courses)
- Finland (2 courses)
- Czech Republic (1 course)
- Greece (1 course)
- UK (1 course)

Based on responses to the Integrated Questionnaire and calls for information 3 INTUITION partners (UPM, UMA, EPFL) have experience of 4 of these programmes in either delivering or attending them.

| Country | Name of course | Where course is delivered | Web address | Email details of course contact | Partners with experience |
|---|---|---|---|---|---|
| Czech Republic | Virtual Reality | Czech Technical University (CTU) | http://cs.felk.cvut.cz/webis/en/courses/P36VR.html | office@cs.felk.cvut.cz | |
| Finland | Virtual Reality (SGN-5406) | Tampere University of Technology | http://pinkpanther.dmi.tut.fi/vr/ | ismo.rakkolainen@tut.fi | |
| Finland | Virtual Reality (T-111.5400) | Helsinki University of Technology | http://www.tml.tkk.fi/Opinnot/T-111.5400/ | Tapio Lokki – Tapio.Lokki@hut.fi | HUT |
| France | Introduction to VR Software INRS | | http://www.simteam.com | | |
| France | Amira/AmiraVR training | Mercury Computer Systems | www.mc.com/tgs | adutarte@mc.com | |

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|---|---|---|---|---|---|
| France | Open Inventor training VR/multipipe option | Mercury Computer Systems | www.mc.com/tgs | adutarte@mc.com | |
| France | Virtual Reality and Mastering of Complex Systems | Université d'Evry Val-d'Essonne | http://univ-evry.fr | fchavand@iie.cnam.fr | |
| Greece | Virtual Reality Haptics and Applications | National Technical University of Athens | http://www.softlab.ece.ntua.gr/~ktzaf/Courses/VR-Haptics-course.html | ktzaf@softlab.ntua.gr | |
| Spain | Computer graphics, systems of geographical information and virtual reality | Escuela Técnica Superior de Ingenieros de Caminos | http://www.unican.es/WebUC/catalogo/doctorado/detalle_curso.asp?id=72002&pr=1202 | gestion.academica@unican.es | |
| Spain | Foundations of the computer graphics | Escuela Técnica Superior de Ingenieros Industriales | http://www.gig.etsii.upm.es/doctorado.htm | gig@etsii.upm.es | UPM |
| Spain | Research on treatments based on virtual reality Doctoral Program on Basic Processes and Intervention in Clinical and Health Psychology. | Universidad de Málaga | http://www.uma.es/petra/doctor.htm | Carmen Rodríguez Naranjo – R_naranjo@uma.es | UMA |
| Spain | Intelligent Virtual Environments | Universidad Politecnica de Madrid | http://www.upm.es | angelica@fi.upm.es | UPM |
| Spain | Representation of 3D objects in animation and virtual reality | Universidad Rey Juan Carlos | http://www.dtf.fi.upm.es/ROTARV.htm | agiraldo@fi.upm.es | UPM |
| Spain | Image Synthesis and Virtual Reality Doctoral Program on Advanced Computing Systems | Universitat Jaume I | http://www.lsi.uji.es/documentos/docs/guia_programa.pdf | Rafael Berlanga – adm-lsi@lsi.uji.es | |
| Spain | Doctoral Program on Software | Universitat Politècnica de Catalunya | http://www.lsi.upc.es/doctorat/soft/esp/index.html | Mercè Juan – merce@lsi.upc.es | |
| Switzerland | VR and Multi-pipe SDK (SGI) Rochettes | | www.sgi.fr | Customer education Tel: (800) 361 2621 | |
| Switzerland | Advanced Virtual Reality Systems and TelePresence | EPFL | http://www.vrlab.epfl.ch | Daniel Thalmann – daniel.thalmann@epfl.ch | EPFL |

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|---|---|---|---|---|---|
| Switzerland | Virtual Reality in Medicine | Polytechnic Federal Institute of Technology (ETH) | http://control.ee.ethz.ch/~ifareg/VR_Course/VRinMedicine.php | Robert.riener@control.ee.ethz.ch<br>Matthias.harders@vision.ee.ethz.ch | |
| UK | Virtual Environments, Imaging and Visualisation | University College London | http://www.cs.ucl.ac.uk/teaching/engd | Anthony Steed –<br>A.Steed@cs.ucl.ac.uk | |

*Table A3: List of Doctoral Programmes.*

# 4. Professional Training Courses

A list of professional training courses is shown in Table 4 below. There are 4 courses listed, 3 which took place in France and 1 in Switzerland. The training took place at 2 of the partners' sites (INRS, MCS).

| Country | Name of course | Where course is delivered | Web address | Email details of course contact | Partners with experience |
|---|---|---|---|---|---|
| France | Introduction to VR Software | INRS | http://www.simteam.com (now closed) | This course were delivered by the Simteam Compagny (now closed). | INRS |
| France | Open Inventor training – VR/multipipe option | Mercury Computer Systems | www.mc.com/tgs | adutarte@mc.com | MCS |
| France | Amira/AmiraVR training | Mercury Computer Systems | www.mc.com/tgs | adutarte@mc.com | MCS |
| Switzerland | VR and Multi-pipe SDK (SGI) | Rochettes | www.sgi.fr | Customer education<br>Tel: (800) 361 2621 | MCS |

*Table A4: List of Professional training courses.*

## 5. Conclusions

In total 182 VR and VR related courses in 19 countries around Europe have been listed. A summary of the types of courses and in which countries they are available is shown in Table 5 below.

| **Country** | Undergraduate | Postgraduate | Doctoral | Professional | **Total** |
|---|---|---|---|---|---|
| UK | 38 | 22 | 1 | | 61 |
| France | 5 | 13 | 4 | 3 | 25 |
| Germany | 15 | 10 | | | 25 |
| Spain | 5 | 3 | 7 | | 15 |
| Switzerland | 4 | 3 | 3 | 1 | 11 |
| Austria | 7 | | | | 7 |
| Czech Republic | 6 | | 1 | | 7 |
| Denmark | 7 | | | | 7 |
| Finland | 3 | 2 | 2 | | 7 |
| Sweden | 7 | | | | 7 |
| The Netherlands | 4 | 3 | | | 7 |
| Greece | 3 | 2 | 1 | | 6 |
| Poland | 6 | | | | 6 |
| Ireland | 1 | 1 | | | 2 |
| Portugal | 1 | 1 | | | 2 |
| Italy | 1 | | | | 1 |
| Norway | 1 | | | | 1 |
| Romania | | 1 | | | 1 |
| Turkey | 1 | | | | 1 |
| | | | | | |
| **Total** | 115 | 61 | 19 | 4 | **199** |

*Table A5: Summary of types of VR and VR related courses by country.*

This appendix provides an update on the list of VR courses as was compiled by Mirabelle D'Cruz and Harshada Patel (2004). Universities, institutes, and companies as depicted on the list were contacted by e-mail. The feedback received was used to update the list. The courses from providers that did not respond, were left unchanged. Moreover, some courses were taken from the list as they are no longer offered, whereas new courses have entered the list that are explicitly focused on VR. Compared to the original list compiled by D'Cruz and Patel (2004), please note especially the substantial modification of the number of PhD courses, going from 10 to 19.

It is not surprising that the top three European countries which deliver VR and VR related courses are the UK, Germany and France. In these countries, VR technologies and virtual environments have been a focus of interest for many years. For this reason the educational systems in these countries recognize the need to develop the appropriate skills required for good design and implementation of VR technologies and applications. In general, the number of courses offered on VR in European countries (less than 200 courses spread over 19 countries; see Table A5) is still rather small.

A recent informal survey of educational courses on VR and related subjects (e.g. human factors, interface design, arts, architecture) showed that only 3% of universities offer such courses, with half of them located in the states (Burdea, 2004). Burdea (2004) highlights a variety of reasons. The VR scientific community is “small and non-homogenous” with few dedicated publications and newsletters. Hence, on the one hand there is a lack of experts available to teach courses, and on the other hand problems arise with respect to communicating between experts form various disciplines in their quest to seek consensus. The latter is illustrated by the lack of standards on software. Moreover, it is expensive for educational institutions to pay for license fees for software; however, free toolkits have the drawback of limited documentation, less support, and limited capabilities. The complexity of this all is enhanced due to the fast development and rapid changes in the field. Therefore textbooks need to be constantly updated, web-based if possible. Finally there is the uncertain job market; the career path is unclear for those who choose to specialize in VR.