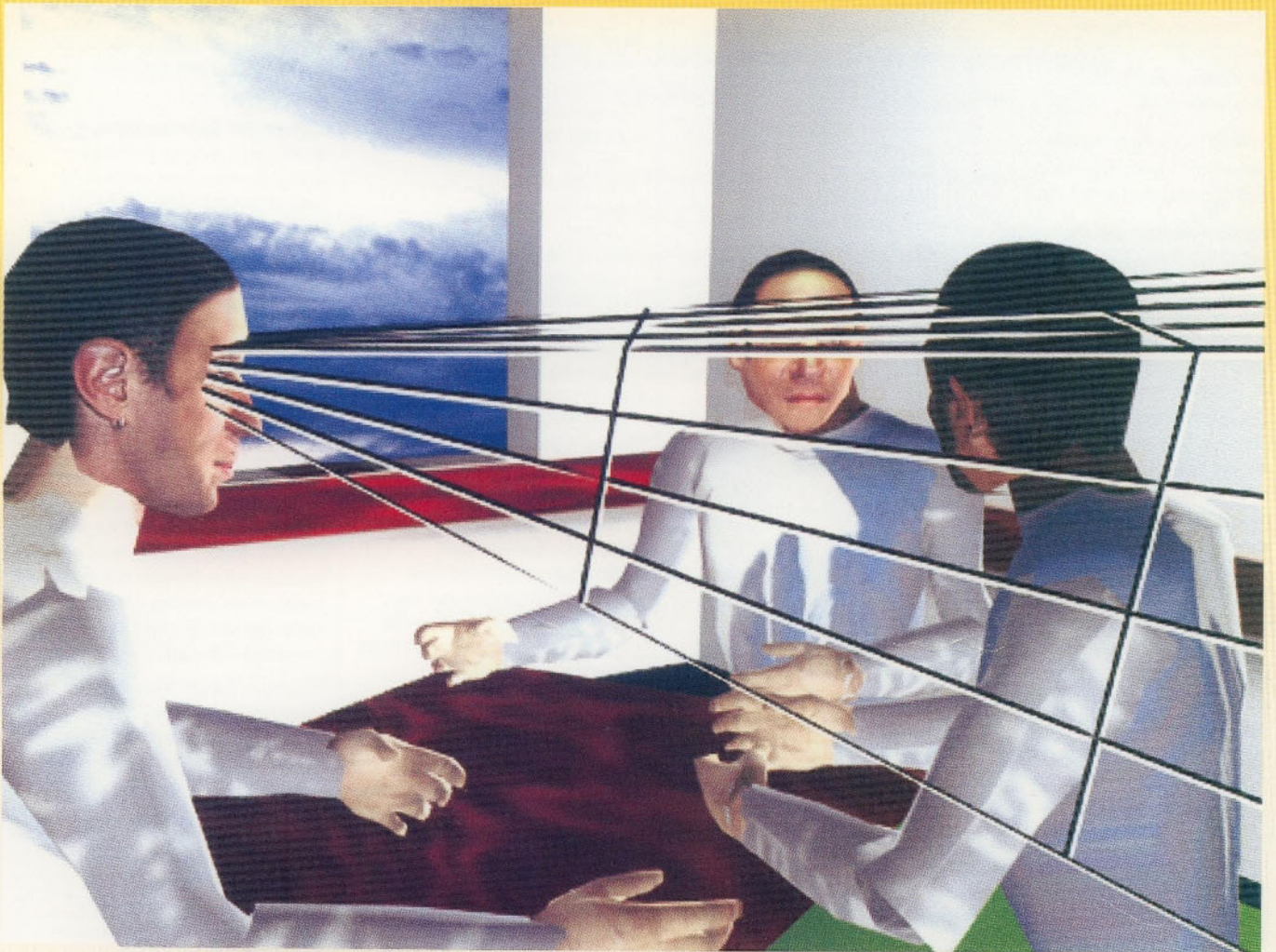


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Teaching Virtual Reality: Why and How?

Abstract

This article looks at the teaching aspects of virtual reality, as opposed to the use of virtual reality as a teaching tool (in virtual teaching environments). It is motivated by a perceived need for clarity, focus, and dialogue that are lacking within the VR community of developers, instructors, and end users. The market for visualization/3D computer graphics/simulations has seen a steady growth over the last decade. Yet, despite success stories in oil exploration, military training, car manufacturing, and other sectors, the VR curriculum has been fragmented and heterogeneous. The most longevity and success has been shown by programs that are designed to satisfy a societal need, such as the MOVES Institute at the Naval Postgraduate School (USA). The difficulty in adequately teaching VR may be related to the expense of setting up dedicated laboratories, and the lack of supporting textbooks in the 1990s. Yet such laboratories and books are key to gaining true understanding of the VR domain. An informal worldwide survey shows that only 3% of universities offer such courses, with half being in the USA. A listing of courses in Core (VR, VE technology) and Related (human factors, interface design, arts, architecture) areas is included in the Appendix. It is hoped that this article will spark a much-needed dialog within the VR community on ways to better teach VR to address societal needs.

I Introduction¹

Virtual reality (VR) is certainly the focus of media and public interest, but after decades of development, VR technology remains largely misunderstood. Why do people have such misconceptions and unreasonable expectations? To some extent this can be blamed on "media hype." Hollywood movies (such as the "Lawnmower Man," and

more recently "The Matrix") lead the public to believe VR can do everything, solve every societal need, change reality forever, and so on. Of course this is pure fantasy. Likely due to these movies the public thinks of VR as head-mounted displays (or "goggles") and sensing gloves. Yet VR is done today mostly on PC screens, and with interactions mediated by computer mice or joysticks. However, professionals (such as manufacturers of VR equipment, and software developers) also have a role.

In other professions and fields of science and engineering, experts play an important role in setting a standard of expectations and performing a societal "reality check." Where is the voice of VR specialists explaining concepts to the public and setting standards of what can and cannot be done with today's VR technology? The truth is the VR scientific community is small and nonhomogeneous, as well as lacking in dedicated publications and newsletters (except for *Presence*). The number of such publications has been steadily declining, and this situation hampers communication and consensus among specialists.

The VR community is small not only because the field is relatively new, but also because it has not been taught adequately at the college level. The vast majority of universities worldwide offer no VR courses. To some extent this used to be due to the specialized equipment needed to teach the subject. This equipment used to be very expensive (\$100,000 was an average equipment cost when setting up a VR laboratory in the 1990s). However, this is no longer the case today, when computer hardware prices have dropped dramatically. Not only have graphics capabilities improved significantly, compared to less than a decade ago, but so has the price/performance ratio of head-mounted displays, sensing gloves, and other VR hardware.

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1. This work is based on a paper with the same title in the *Proceedings of the Symposium on Real World Information Systems*, University of Tokyo, pp. 19–22, September 2003.

The reason so few universities teach VR courses today is probably related to a shortage of faculty with firsthand knowledge of the subject. Such know-how can only be gained through years of research in dedicated facilities (academic, governmental, or industrial research centers), and such laboratories are few in number. Another reason for the scarcity of VR courses used to be the job market, with a career path being unclear for somebody specializing in a VR-related field.

2 Why Should VR be Taught in College?

It is difficult to ascertain at this point what the penetration is (percentage-wise) of VR specialists in the various sectors of the economy. The market for 3D computer graphics, animation, and VR is projected to grow to \$3.54 billion by 2005 (Machover Associates, 2000). A survey done in 2002 by CyberEdge Information Services (2002) estimates there are 650,000 people involved in Visualization/VR/Simulation applications worldwide, most being end users. The job market for VR specialists is improving, as the spectrum of profitable VR applications in all aspects of life is expanding. 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.

An important VR application success story is in the oil exploration industry. Discovery of new oil reservoirs involves drilling exploratory wells, which cost \$10 million each and have a success rate of only 30%. With traditional methods, using databases of seismic waves, only one exploratory well in three finds oil. Virtual reality has been used to help visualize terrain data, and present it to geologists and physicists in 3D. Once such approaches were taken, the success rate grew to 80% (Sanstrom & Langorio, 2002). VR has also been very useful in improving oil extraction rates, such that all necessary VR equipment and software is paid off from the savings in the first well drilled. Therefore all major oil companies have invested heavily in VR and have specialized visualization centers.

Virtual reality has also been increasingly used in defense applications. One example is the Aviation Combat Arms Tactical Trainer in the Army (National Simulation Center, 2002). It allows training of heterogeneous mobile units (such as armor and combat helicopters), with a modular design that allows the change of mission, or tank-helicopter cockpits. Networking several simulators using standard DIS protocols allows complex team training, as seen in Figure 1(a). The savings in training costs, increased safety for the troops, as well as reduced environmental impact are just some of the advantages brought by this VR application.

Another example of VR military use is the VESUB system for Officer of the Deck training (Hays, Vincenzi, Seamon, & Bradley, 1998). It consists of a mockup of a submarine deck, where the trainee wears a tracked head-mounted display, and looks at a virtual harbor scene (as shown in Figure 1(b,c). Interaction with the VE is done through voice commands, 3D sound feedback, and pushbuttons retrofitted on the HMD. These allow zooming on scene details, and create the functionality of binoculars. The system is in current use at the Naval Submarine School in Groton (Connecticut USA). Here it improves the skills of novice officers who otherwise would have little chance of practicing difficult maneuvers on real submarines during harbor approach. Since a submarine is a very expensive (and dangerous) military asset, it is intuitive that improved safety during surface navigation is a very useful contribution of VR-based training.

The military has such a great need and appreciation for VR-VE training and simulations that it created a Master of Science and Doctoral program with this specialty at the Naval Postgraduate School in Monterey (California). This is housed in the Modeling, Simulation, and Virtual Environments (MOVES) Institute and offers a wide array of VR-related courses. This example shows a need-based decision to teach VR in a military college. Since its inception, MOVES has graduated 75 students, and is currently attended by about 40 students (MOVES, 2003). They are doing VR/simulation-related theses, and follow a military career path after graduation (in the army, navy, or marine corps).

Interest is growing around the world in the use of virtual reality in education and training, not just in the



Figure 1. Examples of VR use in the military: (a) Scene from an Aviation Combat Arms Tactical Trainer simulation scenario [National Simulation Center, 2002] © U.S. Army. Reprinted by Permission; (b) VESUB system setup; (c) scene showing a harbor navigation task [Hays et al., 1998]. Photos (b) and (c) by Don Smith DFC. Reprinted by permission.

military, but also in civilian education (from kindergarten to 12th grade). The development of VEs suited for educational use and the training of schoolteachers in how to use the new technology is the focus of a program offered by the College of Education at East Carolina University (North Carolina). The organization of VR courses is again need-based, consisting of distance-learning introductory and advanced courses at the undergraduate, graduate, and continuing-education levels. The undergraduate-graduate courses form VR concentrations (now in the process of being redesigned). The distance learning component awards a Certificate in Virtual Reality in Education and Training. The VR concentrations/distance learning programs have been attended by close to 1,000 students since their introduction 10 years ago. Other universities have followed this trend,

with VR-VE Master and Doctorate degrees being offered by some European universities (notably in the United Kingdom and France).

3 Teaching Virtual Reality

A critical part of teaching VR at the college level is the textbook used. Many books have been written about VR, including journalistic essays, science fiction, and technical books. The latter category includes *Virtual Reality: Through the New Looking Glass* (Pimentel & Teixeira, 1993), and *The Science of Virtual Reality and Virtual Environments* (Kalawsky, 1993). More recently these were followed by *Understanding Virtual Reality* (Sherman & Craig, 2003),

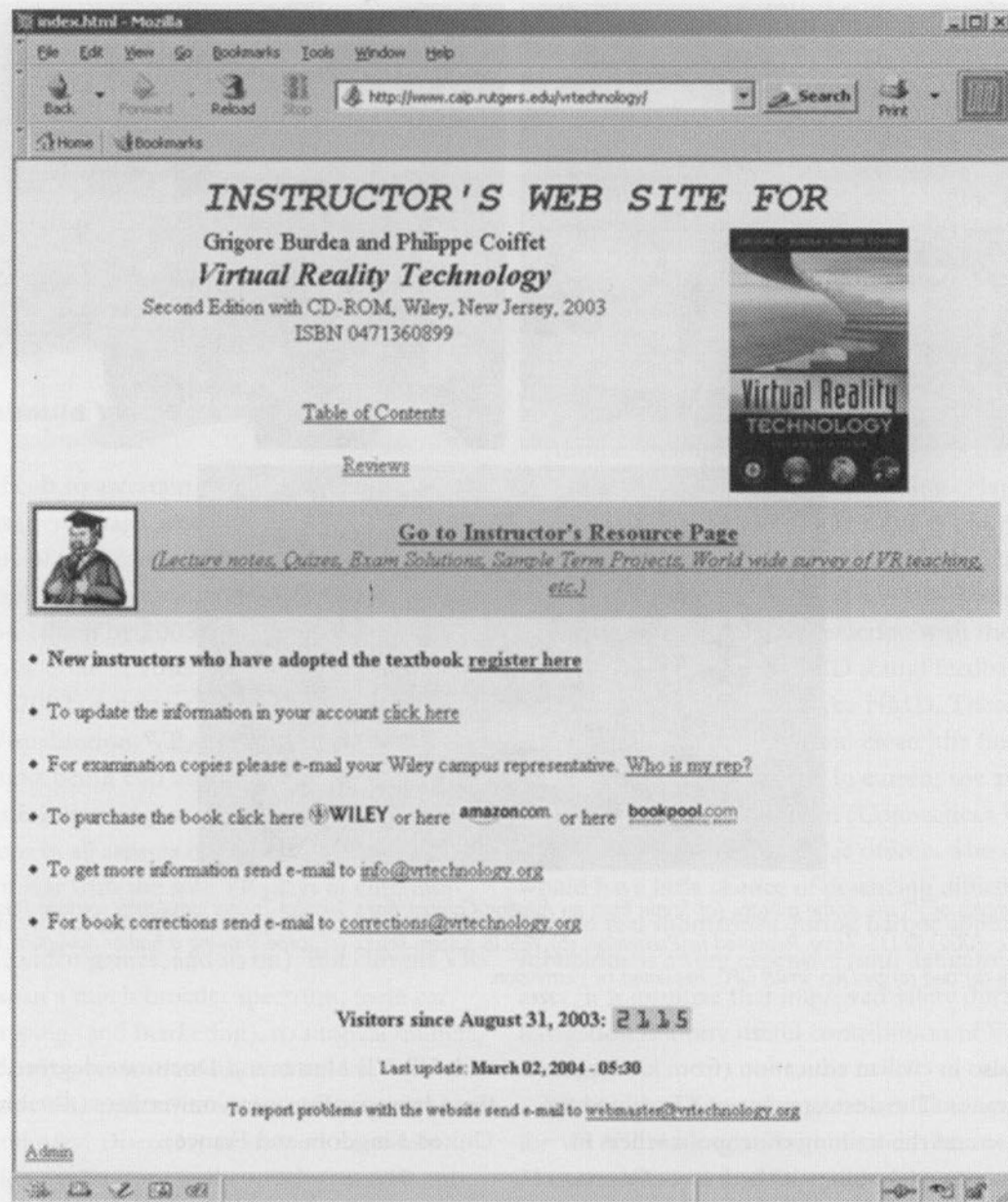


Figure 2. An example of Instructor's Resources site for teaching VR (www.vrtechnology.org). © 2003, 2004 Grigore Burdea. Reprinted by permission.

and *Virtual Reality Technology* (Burdea and Coiffet, 2003). A good textbook needs to have quiz questions and a CD-ROM with movies. This is necessary due to the visual nature of VR, which cannot be adequately conveyed solely through text. Since the field changes so fast, instructors need to constantly update their lectures. This task is made easier if a Web site for instructors using a particular textbook exists. This is the

place where an author can post updated materials, and provide other teaching resources. An example is shown in Figure 2.

Just as important, modern VR textbooks should have a laboratory manual with homework and programming assignments, which are necessary in teaching students the intricacies of real-time programming. VR cannot be taught adequately without a specialized laboratory. Universities

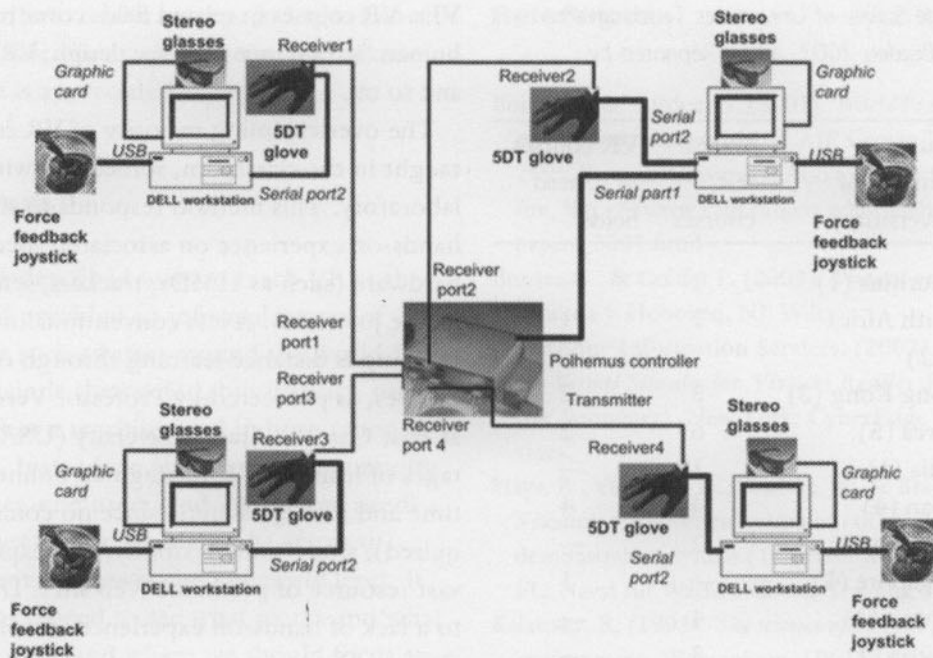


Figure 3. A "cell" in the Virtual Reality Teaching Laboratory of the ECE Department at Rutgers University. © Rutgers University. Reprinted by permission.

need to compromise between the number of potentially interested students and the number of VR workstations available to them. A solution is to use these laboratory workstations repeatedly during several sessions in a week. A VR class that enrolls, say, 60 students, could then have 5 laboratory sections, each with 12 students, each using the teaching laboratory once every week.

Another compromise relates to multiplexing expensive hardware, such as 3D trackers. If trackers are purchased with multiple sensors (receivers), then one sensor can be assigned for every workstation, and the same tracker electronics and source used by several students simultaneously. The drawback is an increase in tracker latency, since the number of data sets/second may drop with the increase in number of sensors (for Polhemus-type trackers). Furthermore, the network traffic to transmit such data over the laboratory LAN increases. A hardware configuration that implements this laboratory concept is shown in Figure 3 (Burdea & Coiffet, 2003). This method was tested on hundreds of students taking the author's VR course over the last couple of years. It is by no means the only possible configuration.

Finally, it is not practical to have universities pay

for software licenses needed to run VR toolkits, such as WorldToolKit (Sense8, 2001). Instead, VR programming assignments should be done in VRML, Java 3D, or other toolkits that are in the public domain. One question arises, namely, "Is there a performance penalty in using these free toolkits?" Java 3D, for example, has been shown to have the same (or better) performance than WTK, in terms of frame refresh rates and latencies (Boian & Burdea, 2001). The drawback in using free software is less documentation and less support for more sophisticated VR interfaces. Thus, manuals for VR teaching laboratories using public domain toolkits need to include software drivers for trackers, sensing gloves, and active glasses, to help novice students in their programming assignments.

4 A Worldwide Survey of Universities Teaching VR

Table 1 summarizes an informal Web-based survey of universities teaching VR courses around the world. Core courses are those that present the technology and programming aspects of stand-alone or networked VR/

Table 1. *Worldwide Survey of Universities Teaching VR Courses.* © Grigore Burdea 2003, 2004. Reprinted by Permission.

Continent	Country (number of universities)	Core VR courses	VR courses in related fields
Africa (3)	Mauritius (1)	1	—
	South Africa (2)	1	1
Asia (20)	Hong Kong (3)	3	2
	Korea (5)	6	2
	India (1)	1	—
	Japan (4)	4	4
	Malaysia (2)	2	—
	Singapore (1)	—	1
	Taiwan (4)	4	—
Europe (52)	Austria (1)	3	—
	Czech Republic (1)	3	1
	Denmark (1)	2	—
	Finland (3)	3	—
	France (5)	5	—
	Germany (7)	4	4
	Greece (2)	1	2
	Holland (3)	—	3
	Norway (1)	—	1
	Spain (1)	—	1
	Sweden (4)	3	1
	Switzerland (1)	1	—
	UK (22)	19	10
North America (64)	Canada (5)	4	2
	Mexico (2)	1	1
	US (57)	59	37
Oceania (1)	Australia (1)	—	1
South America (8)	Brazil (3)	3	1
	Colombia (3)	2	1
	Peru (2)	1	1
Total	148	136	77

VEs. VR courses in related fields cover topics such as human factors, user interface design, VR in Animation, and so on.

The overwhelming majority of VR courses are taught in the classroom, sometimes with an associated laboratory. This method responds to the need to have hands-on experience on associated specialized VR hardware (such as HMDs, trackers, sensing gloves, or haptic joysticks). A less conventional method of teaching is distance learning through online VR courses, as pioneered by Professor Veronica Pantelidis at East Carolina State University (USA). The advantages of learning VR through an online course are time and money savings (since no commuting is required), study-time flexibility, and exploitation of a vast resource of pertinent Web sites. Drawbacks relate to a lack of hands-on experience (for the student) and time required to answer large amounts of email (for the instructor) (Pantelidis & Auld, 2003).

Looking at the data presented in Table 1, it can be seen that North American universities have been at the forefront of VR teaching, which is not surprising owing to the fact that the United States was a pioneer in this field. Canada, the United States, and Mexico together account for 64 universities, which is 43% of the 148 universities identified in the survey. The second largest group is 52 European universities, mostly in the United Kingdom (again not surprising, due to that country's early contributions to the field). Asia (20), South America (8), Africa (3), and Oceania (1) follow. These numbers may underestimate the true contribution of continents such as South America, since universities in non-English speaking countries did not have their Web sites "hit." Nonetheless, assuming approximately 100% undercount in South America, Africa, and Oceania, the total number of universities teaching VR worldwide would be about 160. This is only 3% of the approximately 4,500 universities and colleges existing in the world. Specialized VR teaching laboratories (not VR research laboratories) are even less numerous. A detailed course listing (including university name, course title, and URL) can be found in Table 2 (Appendix). Readers

wishing to contribute to the survey, and who know of VR courses not listed here, should contact the author. Their help is appreciated.

5 Conclusions

This article described ways to teach VR at the college level and provided an informal survey of universities offering such courses around the world. This focus did not include the related, but distinct, topic of the use of VR as a teaching tool in both schools and universities. Instead we feel that the community of VR researchers, end users, and instructors needs a discussion catalyst on the ways and the status of teaching pertinent courses at the university level. It was motivated by a need to see what works and what does not in our field, and where we should focus attention when it comes to preparing quality graduates that have a productive VR-related career path. It is hoped that a true and fruitful dialog will ensue within our community.

Request to Readers

The table in the Appendix to this article lists courses that were identified by the author at the time of publication. The listed URLs are accurate as of March 8, 2004. An up-to-date table is maintained on the author's Web site (<http://www.caip.rutgers.edu/vrtechnology/resources/public/survey.html>). Readers who find that their course is not listed in this table are asked to kindly email the author with their country, university name, course title, and course URL.

Acknowledgments

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Appendix

Table A1. Detailed Survey of VR Courses Taught at Universities Worldwide Copyright © Grigore Burdea, 2003, 2004

Country and University (alphabetical)	Course name and URL (C-Core, R-related fields)
Australia James Cook University	CP 1010 Introduction to Multimedia R http://www.it.jcu.edu.au/Subjects/cp1010/2001/lectures/Lect25 VR.html
Austria Vienna University of Technology	LU Virtual Reality C http://www.ims.tuwien.ac.at/teaching_detail.php?ims_id=186057 VO Virtual Reality C http://www.ims.tuwien.ac.at/teaching_detail.php?ims_id=186056 VU Special Topics in Virtual Reality C http://www.cg.tuwien.ac.at/courses/SpecialTopicsVR/VU.html
Brazil Faculdade Michelangelo	Human-Machine Interface and Virtual Reality R http://www.michelangelo.edu.br/Gra-SistemasDeInfo-GradeCurric.asp
Brazil Universidade do Sao Paulo	PSI 5787 Virtual Reality C http://www.lsi.usp.br/~mkzuffo/PSI5787
Brazil Universidade Federal do Rio de Janeiro	COC785 Introduction in Virtual Reality C http://www.lamce.ufrj.br/GRVa/coc785.html COC 769 Advanced Techniques in VR C http://www.lamce.ufrj.br/GRVa/coc769
Canada Ecole de Technologie Superieure	MGL820 Human-Machine Interface R http://www.etsmtl.ca/zone2/programmes/2e_3e_cycles/maitrise/3822.html#5
Canada McGill University	416650B Consciousness, Virtual Reality and Cyberspace R http://www.education.mcgill.ca/profs/cartwright/edpe650/
Canada Simon Fraser University Surrey	ITEC 615 Virtual Reality C http://www.surrey.sfu.ca/grad/currentCourses.html
Canada University of Alberta	CMPUT 612 Virtual Reality C http://www.cs.ualberta.ca/~qiongyan/612proj.htm CMPUT 613: Sensor Based Geometric Modeling for Virtual Reality Applications C http://www.cs.ualberta.ca/~pierre/CMPUT613
Canada University of Ottawa	ELG 5124 (92.524) Virtual Environments C http://www.site.uottawa.ca/%7Epetriu/ELG5124-Sylab2003.pdf

NOTE. The course URLs are accurate as of March 8, 2004. An up-to-date table can be found at <http://www.caip.rutgers.edu/vrtechnology/resources/public/survey.html>

Country and University (alphabetical)	Course name and URL (C-Core, R-related fields)
Czech Republic Czech Technical University	<i>PGR012 Virtual Reality C</i> http://www.cgg.cvut.cz/~zara/PGR012/ <i>PA 111VR Programming C</i> http://www.cgg.cvut.cz/~zara/PA111/ <i>Virtual Reality (graduate) C</i> http://www.cgg.cvut.cz/~zara/P36VR/ <i>36 MUS Multimedia Systems R</i> http://cs.felk.cvut.cz/webis/en/courses/36MUS.html
Colombia EAFIT	<i>ST216 Distributed VR C</i> http://arcadia.eafit.edu.co
Colombia Pontificia Universidad Javeriana	<i>CC070 Computer Graphics and Virtual Environments R</i> http://ingenieria.puj.edu.co/sistemas/cursos/CC070.html
Colombia Universidad de los Andes	<i>ISIS380-Virtual Reality Techniques C</i> http://agamenon.uniandes.edu.co/~fde/isis380-2003-2
Denmark Aalborg University	<i>Virtual Reality I, II C</i> http://www.cvmt.auc.dk/~cbm/teaching/vr/vr.html
Finland Helsinki University of Technology	<i>T-111.400 Virtual Reality C</i> http://www.tml.hut.fi/Studies/T-111.400/
Finland University of Oulu	<i>81524S Virtual Reality C</i> http://www.tol.oulu.fi/~tmannine/vrt/
Finland University of Turku	<i>Special Course on Networked Virtual Environments C</i> http://staff.cs.utu.fi/kurssit/scnve/spring_2002/
France Ecole de Mine de Paris	<i>S1833 Scene generation in Virtual Reality C</i> http://www.ensmp.fr/Fr/Formation/2emeCycle/IngCivil/Enseignement/Ens-S1833.html
France Ecole Nationale d'Ingénieurs de Brest	<i>Master in VR C</i> http://www.enib.fr
France Institut des Sciences et Techniques de l'Ingénieur d'Angers	<i>Master in VR C</i> http://www.istia.univ-angers.fr
France Institut Image	<i>Master in VR C</i> http://www.ai.cluny.ensam.fr
France Université Paris Sud	<i>Fundamentals of Virtual Reality and Advanced Interfaces C</i> http://www.lri.fr/DEA/13/opt11.html
Germany Darmstadt University of Technology	<i>Visualization and Virtual Reality R</i> http://www.tu-darmstadt.de/vvss98/comments/20.133.en.html

Country and University (alphabetical)	Course name and URL (C-Core, R-related fields)
Germany University of Applied Sciences Bonn-Rhein-Sieg	<i>WS2003/2004-Advanced virtual environments</i> C http://www2.inf.fh-bonn-rhein-sieg.de/~ahinke2m/ <i>Master in virtual environments</i> C http://www2.inf.fh-bonn-rhein-sieg.de/~ahinke2m/
Germany University of Erlangen-Nuremberg	<i>Interactive Computer Graphics</i> R http://www9.informatik.uni-erlangen.de/Teaching/SS2003/InCG
Germany Universität Koblenz-Landau	<i>Virtual and Augmented Reality</i> C http://www.uni-koblenz.de/~cg/veranst/ss03/vrar.html
Germany University of Stuttgart	<i>Graphical-Interactive Systems</i> R http://www.vis.uni-stuttgart.de/eng/teaching/lecture/ws03/gis/
Germany University of Tuebingen	<i>Computer Graphics</i> R http://www.gris.uni-tuebingen.de/
Germany University of Weimar	<i>SS200 Virtual Environments-Technology and Systems</i> C http://xyz.scc.uni-weimar.de/medien/vr/lectures/SS2003/index_en.htm
Greece Aristotle University of Thessaloniki	<i>09-Virtual Reality</i> C http://www.csd.auth.gr/personnel/info.en.php?id=nikolaid
Greece University of Ioannina	<i>Educational Virtual Environments</i> R <i>Virtual Realities in Education</i> R http://www.primary.edu.uoi.gr/earth_lab/index_en.htm
Holland University of Amsterdam	<i>Scientific Visualization and Virtual Reality</i> R http://info.science.uva.nl/research/scs/edu/scivis
Holland Universiteit Utrecht	<i>Masters in Geometry, Imaging and Virtual Environments</i> R
Holland Vrije Universiteit Amsterdam	<i>Multimedia Authoring II—Virtual Environments</i> R http://wasp.cs.vu.nl/mma2/index.htm
Hong Kong Chinese University of Hong Kong	<i>CSC 5460 Advanced Topics in Virtual Reality</i> C <i>CSC 7242 Web-based Graphics & VR Systems</i> R http://appsrv.cse.cuhk.edu.hk/~csc5460
Hong Kong City University of Hong Kong	<i>SM5311 Virtual Reality</i> C http://www.cityu.edu.hk/scm/program/courses/sm5311.pdf <i>IT 6304 Selected Topics on Virtual Reality</i> C http://www.it.cityu.edu.hk/~itaku/vr.htm
Hong Kong The University of Hong Kong	<i>CSIS7501—Advanced computer graphics and virtual reality</i> R http://msecs.csis.hku.hk/public/courses/CSIS7501.htm

Country and University (alphabetical)	Course name and URL (C-Core, R-related fields)
India Indian Institute of Science	<i>E0 272 Topics in Virtual Reality C</i> http://csa.iisc.ernet.in/academics/curriculum/
Japan Tokyo Institute of Technology	<i>Virtual World Systems C</i> http://www.dis.titech.ac.jp/syllabus_e.html
Japan Tokyo Metropolitan Institute of Technology	<i>Mechano-informatics systems R</i> http://www.tmit.ac.jp/kyoumu/kamoku_ichiran.htm#seisan (Japanese) <i>Human Interface R</i> http://www.tmit.ac.jp/kyoumu/kamoku_ichiran.htm#seisan (Japanese) <i>Information Environments R</i> http://www.tmit.ac.jp/kyoumu/kamoku_ichiran.htm#seisan (Japanese) <i>Virtual Reality C</i> No web page
Japan University of Tokyo	<i>Introduction to Robotics and Virtual Reality C</i> http://www.gavo.t.u-tokyo.ac.jp/index-e.html
Japan University of Tsukuba	<i>Virtual Reality C</i> http://www.riko.tsukuba.ac.jp/lectures.html <i>Advanced Human Interface R</i> http://www.esys.tsukuba.ac.jp/graduate/classE.html
Korea Ewha Women's University	<i>IT429 Topics in Virtual Reality C</i> http://home.ewha.ac.kr/~jooypark/class/2004-1-VR/index.html
Korea Hanyang University	<i>CSE977 Virtual Reality C</i> http://mr.hanyang.ac.kr/VR
Korea Korean Advanced Institute of Science and Technology (KAIST)	<i>CS 788 Topics in HCI (Virtual Reality) C</i> http://vr.kaist.ac.kr/courses/cs778/cs778.html
Korea Kwangju Institute of Science and Technology (KJIST)	<i>Virtual Environment and Haptics C</i> http://dyconlab.kjist.ac.kr <i>DIC1623 Networking Application Design R</i> http://netmedia.kjist.ac.kr/courses/dic1623-2002fa/overview.htm <i>DIC1693 Human Computer Interaction R</i> http://vr.kjist.ac.kr/~Class/DIC1693/
Korea Pohang University of Science and Technology	<i>CSE 511: Introduction to Virtual Reality C</i> http://www.postech.ac.kr/~gkim/cse511/cse511home.html <i>CSE 615 Advanced Topics in Virtual Reality C</i> http://www.postech.ac.kr/~gkim/cse615/cse615home.html

Country and University (alphabetical)	Course name and URL (C-Core, R-related fields)
Malaysia Multimedia University	<i>TVR3101 Virtual Reality C</i> http://fit.mmu.edu.my/syllabusnd/syllabus/TVR3101.html
Malaysia Universiti Teknologi PETRONAS	<i>STB 5023 Virtual Reality C</i> www.utp.edu.my/elearning.htm
Mauritius University of Mauritius	<i>CSE 3009 Virtual Reality Systems C</i> http://www.uom.ac.mu/Faculty/FOE/courselist/e312.htm#listmod
Mexico Universidad Nacional Autonoma de Mexico	<i>0059 Advanced Computer Graphics and Virtual Reality R</i> http://www.fcencias.unam.mx
Mexico University of the Americas in Puebla	<i>Foundations of Virtual Reality C</i> http://mail.udlap.mx/~aguilera/dir/Cursos/RV/TemarioVR.html
Norway Norwegian University of Science and Technology	<i>VRML in Chemistry R</i> http://pcfl.chembio.ntnu.no/~bka/div/vrml/moldyn.htm
Peru Universidad Alas Peruanas	<i>Ofimática avanzada para ingenieros R</i> http://www.uap.edu.pe/Fac/02/syllabus/02120.pdf
Peru Universidad Ricardo Palma	<i>Virtual Reality C</i> http://www.urp.edu.pe/
Singapore National University of Singapore	<i>IC52A3 Advanced Computer Graphics and Virtual Reality R</i> http://www.comp.nus.edu.sg/~huangzy/ic52a3_syllabus.txt
South Africa Rhodes University	<i>Computer Graphics R</i> http://www.cs.ru.ac.za/courses/Handbook/2003/postgraduate.pdf
South Africa University of Cape Town	<i>Introduction to Collaborative Virtual Environments C</i> http://people.cs.uct.ac.za/~dnunez/honsvr/introCVE.pdf
Spain Universidad Rey Juan Carlos	<i>VR and Animation R</i> http://www.urjc.es/cat/catalogo.pdf
Sweden Linköpings University	<i>Programming 3D Graphics and Virtual Reality R</i> http://www.ida.liu.se/~vaden/gl/
Sweden Lluleå University of Technology	<i>SMM003 Virtual Environments C</i> http://www.luth.se/publ/stuka/2001/3210/KSMM003.en.htm
Sweden Malardalen University/IDP	<i>CT3430 Introduction to Virtual Reality C</i> http://www.idt.mdh.se/kurser/ct3430
Sweden Umeå University	<i>TDBD 12 Virtual Reality C</i> http://www.cs.umu.se/kurser/TDBD12

Country and University (alphabetical)	Course name and URL (C-Core, R-related fields)
Switzerland Polytechnic Institute of Lausanne (EPFL)	<i>Virtual Reality and Multimodal Interaction C</i> http://ic2.epfl.ch/postgr/descr2002/DT2002.html
Taiwan Chaoyang University of Technology	<i>Virtual Reality C</i> http://www.cyut.edu.tw/eindex.htm
Taiwan Da-Yeh University	<i>IFN1006 Virtual Reality C</i> http://www.dyu.edu.tw/~swang/VR/VR_index.htm
Taiwan National Chiao Tung University	<i>Introduction to Virtual Reality C</i> http://cggmwww.csie.nctu.edu.tw
Taiwan National Taiwan University	<i>Raster Graphics—Virtual Reality C</i> http://www.cmlab.csie.ntu.edu.tw/~ming/courses/rg
UK Brunel University	<i>EE3105 3D Graphics, Virtual Reality & Animation R</i> http://www.brunel.ac.uk/admin/registry/module/curr/module_detail_si/EE3105.shtml
UK Loughborough University	<i>COP 381 Virtual Reality C</i> http://www.lboro.ac.uk
UK Napier University	<i>CO42001: Virtual Environments C</i> http://www.soc.napier.ac.uk/module/op/onemodule/moduleid/CO42001/
UK Sheffield Hallam University	<i>Virtual Reality C</i> http://www.shu.ac.uk/schools/cms/teaching/db/VR/index.htm
UK Staffordshire University	<i>GG46 Simulation and Virtual Reality C</i> http://www.staffs.ac.uk/courses/undergrad/course-information.php?course_id=530
UK University of Birmingham	<i>Human-Centered Design and Methodologies R</i> http://www.eng.bham.ac.uk/eece/pg/MS_C_MultiEng.pdf <i>Introduction to Virtual and Synthetic Environments C</i> (no Web page) <i>EE3K1 Future Interactive Systems R</i> http://www.eng.bham.ac.uk/eece/ug/cee/Level_3_modules.htm#EEM3K
UK University of Bradford	<i>Creating Virtual Reality C</i> http://sipr.admin.brad.ac.uk/ipp_pages/00000603.htm
UK University of Bristol	<i>COMS M0105: Visualization and Virtual Reality C</i> http://www.cs.bris.ac.uk/Tools/Local/Handbook/Units/COMSM0105.html

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UK University College London	<i>4C76/VE Virtual Environments C</i> http://www.cs.ucl.ac.uk/teaching/VE <i>Master in VR Studies—Architecture R</i> http://www.bartlett.ucl.ac.uk/graduate/programmes/engd.htm <i>MSc in Vision Imaging and Virtual Environments C</i> http://www.cs.ucl.ac.uk/teaching/VIVE <i>EngD in Virtual Environments, Imaging and Visualisation C</i> http://www.cs.ucl.ac.uk/teaching/engd
UK University of Durham	<i>IDS MSc Visualisation and VR for Distributed Systems C</i> http://www.dur.ac.uk/computer.science/
UK University of Greenwich	<i>COMP1048 Virtual Reality Technology C</i> http://cms1.gre.ac.uk/programmes/cms/coursespecs/COMP1048.doc
UK University of Huddersfield	<i>Virtual Reality Design C</i> http://www.hud.ac.uk/u_grad/eng/virtual.html
UK University of Hull	<i>MSc in Virtual Environments and Visualization C</i> http://www.graphicsmsc.com/
UK University of Leeds	<i>SI31 AGR Advanced Computer Graphics R</i> http://www.comp.leeds.ac.uk/royr/gi31/ <i>AGR Advanced Computer Graphics and Virtual Environments R</i> http://www.comp.leeds.ac.uk/royr/gi31/
UK University of Manchester	<i>CS638 Advanced Virtual Environments C</i> http://www.cs.man.ac.uk/Study_subweb/Postgrad/ACS_CS/webpages/syllabus/acs/CS638.html
UK University of Nottingham	<i>G52UID User Interface Design R</i> http://www.crg.cs.nott.ac.uk/~sdb/uid/
UK University of Portsmouth	<i>455 Computer Animation and Virtual Reality R</i> http://www.tech.port.ac.uk/tud/db/UnivPort/level_3/CG_ANMVR.htm
UK University of Salford	<i>Master in VE C</i> http://www.nicve.salford.ac.uk/teaching <i>PgDip Virtual Environments C</i> http://www.nicve.salford.ac.uk/msc.html
UK University of Sheffield	<i>COM 360 Computer Games Technology R</i> http://www.dcs.shef.ac.uk/teaching/modules/level3/com3160.html <i>3D Computer Graphics R</i> http://www.dcs.shef.ac.uk/teaching/modules/level3/com3150.html
UK University of Sussex	<i>Virtual Reality Systems, Virtual Environments C</i> http://www.sussex.ac.uk/informatics/920G5.html

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UK University of Teesside	<i>GG46 BSc/VR Virtual Reality C</i> http://wheelie.tees.ac.uk/courses/degree/virt_real.html
UK University of Wales, Bangor	<i>M.Sc Advanced Visualization Virtual Environments and Computer Animation C</i> http://www.hpv.informatics.bangor.ac.uk/msc.html
US Bowling Green State University	<i>ARTC 400 Art and Virtual Environments R</i> http://art.bgsu.edu/~glittle/495_sylla.html
US Brown University	<i>CS196-2 Virtual Reality: Immersion, Decisions, Empathy R</i> http://www.cs.brown.edu/courses/cs196-2
US California State University, Fresno	<i>CTET 229: Designing Virtual Realities for Education R</i> http://education.csufresno.edu/facstaf/syllabus/is229_s03_rb.pdf
US California State University, Northridge	<i>CS 565 & CS 565L Advanced Computer Graphics R</i> http://www.csun.edu/~renzo/cs565/565syllabus.htm
US Carnegie-Mellon University	<i>ETC 53-831 Building Virtual Worlds C</i> http://www.alice.org/bvw03/ <i>39-245 Rapid Design through Virtual and Physical Prototyping R</i> http://www-2.cs.cmu.edu/~rapidproto/home.html
US City University of New York	<i>CIS 54 Innovative Approaches to Computer-Human Interfaces R</i> http://acc6.its.brooklyn.cuny.edu/~lscarlat/interface/CIS54syllabus.html
US Clemson University	<i>CS 411, 611 Virtual Reality Systems C</i> http://www.cs.clemson.edu/html/syllabi.cpsc411.shtml
US College of the Atlantic	<i>Virtual Worlds C</i> http://www.coa.edu/barkey/syllabi/vwsy101.html
US East Carolina University	<i>EDTC 2240—Virtual Reality: Introduction and Basic Applications C</i> http://www.coe.edu/vr/6242/edtc2240cshp.html <i>EDTC 3242—Graphics-Based Virtual Environments I C</i> http://www.coe.edu/vr/6242/edtc3242cshp.html <i>EDTC 3243—Graphics-Based Virtual Environments II C</i> http://www.coe.edu/vr/vrclass.htm <i>EDTC 3244—Virtual Reality in Education R</i> http://www.coe.edu/vr/vrclass.htm <i>EDTC 3245—Text-Based Virtual Environments C</i> http://www.coe.edu/vr/vrclass.htm <i>EDTC 3903—Special Topics: Virtual Reality Hardware and Software C</i> http://www.coe.edu/vr/6242/edtc3903cshp.html <i>EDTC 4246—Interactive Three-Dimensional Internet Applications R</i> http://www.coe.edu/vr/vrclass.htm

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	<p><i>EDTC 4900—Seminar on Virtual Reality C</i> http://www.coe.ecu.edu/vr/vrclass.htm</p> <p><i>EDTC 6240—Virtual Reality: Principles and Applications C</i> http://www.coe.ecu.edu/vr/6242/edtc6240hp.html</p> <p><i>EDTC 6242—Building and Using Graphic-Based Virtual Environments for Education R</i> http://www.coe.ecu.edu/vr/6242/edtc6242hp.html</p> <p><i>EDTC 6244—Building and Using Text-Based Virtual Reality Environments for Education R</i> http://www.coe.ecu.edu/vr/6242/edtc6244hp.html</p> <p><i>EDTC 6848—Seminar on Virtual Reality and Education R</i> http://www.coe.ecu.edu/vr/6242/edtc6848hp.html</p>
US George Mason University	<p><i>INFT 852-Graphical Real-time Simulation: A Special Topic On Virtual Reality C</i> http://cs.gmu.edu/~jchen/cs852/cs852-chen.s04.html</p>
US George Washington University	<p><i>CSCI 368 Advanced Topics in Computer Animation and Virtual Reality R</i> http://cs.seas.gwu.edu/graduate/courses/368.html</p>
US Georgia Tech	<p><i>CS 7497 Virtual Environments C</i> http://www.cc.gatech.edu/classes/AY2002/cs7497_spring/</p> <p><i>CS 4750B Human-Computer Interface Design and Evaluation R</i> http://www.cc.gatech.edu/classes/AY2001/cs4750b_fall</p> <p><i>COA 8902 Design & Evaluation of Virtual Environments: or Is Virtual Space Real? C</i> http://undertow.arch.gatech.edu/homepages/rdalton/DOE_syllabus.htm</p>
US Hanover College	<p><i>CS 360 Interactive Computer Graphics R</i> http://www2.hanover.edu/cliburn/360/360syllabusS03.html</p>
US Indiana University/Purdue University (IUPUI)	<p><i>CSCI N355 Virtual Reality C</i> http://www.cs.iupui.edu/~aharris/vrml/vrsyl.html</p> <p><i>CS 360 Interactive Computer Graphics R</i> http://www2.hanover.edu/cliburn/360/360syllabusS03.html</p>
US Iowa State University	<p><i>CPRE 575 Introduction to Virtual Reality C</i> http://ecpe.ee.iastate.edu/newweb/courses/cpre.htm</p> <p><i>CSI/INFT 979 Virtual Reality/Scientific Visualization R</i> http://www.galaxy.gmu.edu/stats/syllabi/inft979.98.html</p> <p><i>IE 584X Virtual Environments and Applications C</i> http://www.lifelearner.iastate.edu/courses/fall03/ie.htm#584</p>

 Country and University (alphabetical) Course name and URL (C-Core, R-related fields)

US Ithaca College	<i>CS 475 Senior Project C</i> http://www.ithaca.edu/faculty/sstansfield/topLevel/availProjects.html
US Johns Hopkins University	<i>530.651 Haptics for Virtual Reality C</i> http://pegasus.mc.jhu.edu/~allisono/courses/530.651/ <i>Comp 600.460 Virtual Worlds C</i> http://www.cs.jhu.edu/~cohen/VW2000/syllabus.html
US Kennesaw State University	<i>IS 8120 Human Computer Interface Design R</i> http://science.kennesaw.edu/csis/msis/courses/is8120.htm
US Lehigh University	<i>CSC 498 Virtual Environments C</i> http://www.cse.lehigh.edu/~dkessler/CSC498/S01/syllabus.html
US Massachusetts College of Art	<i>TDA 319X Computers for Object Makers R</i> http://babel.massart.edu/~joewood/TDA319
US Massachusetts Institute of Technology	<i>16.431 Flight Simulation and Virtual Environments R</i> http://web.mit.edu/sgt/www/evals/97Spring/16431.html
US Millersville University	<i>CS 375 Computer Graphics and Virtual Reality R</i> http://cs.millersville.edu/~webster/cs375/ <i>CS406 Topics in Computer Science: Haptics Programming Environments R</i> http://www.nps.navy.mil/ofcinst/crs_mv.htm http://cs.millersville.edu/~webster/cs406haptics/
US National University	<i>IT625 Simulations and Virtual Reality C</i> http://www3.nu.edu/schools/SOAS/DOWC/courses/IT625.html
US Naval Postgraduate School	<i>MV 2920 Introductory Topics in Modeling, Virtual Environments and Simulation C</i> http://www.movesinstitute.org/courses.html <i>MV 3472 Graphical Simulation of Physical Systems in Virtual Worlds R</i> http://www.movesinstitute.org/courses.html <i>MV 3800 Directed Study in Modeling, Virtual Environments and Simulation C</i> http://www.movesinstitute.org/courses.html <i>MV 3920 Topics in Modeling, Virtual Environments and Simulation C</i> http://www.movesinstitute.org/courses.html <i>MV 4001 Human Factors in Virtual Environments R</i> http://www.movesinstitute.org/courses.html <i>MV4002 Training in Virtual Environments R</i> http://www.nps.navy.mil/ofcinst/crs_mv.htm

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	<i>MV 4015 Agent-Based Autonomous Behavior for Simulations R</i> http://www.complexityandpolicy.org/images/readinglist.pdf
	<i>MV 4204 Computer Graphics Using VRML and X3D R</i> http://www.stl.nps.navy.mil/~brutzman/vrml/MV4204SyllabusJuly2003.pdf
	<i>MV 4472 Advanced Physically Based Modeling R</i> http://www.movesinstitute.org/courses.html
	<i>MV4473 Virtual World & Simulation Systems C</i> http://www.movesinstitute.org/~mcdowell/mv4473
	<i>MV 4474 Virtual Environment Network and Software Architectures C</i> http://www.movesinstitute.org/~zyda/courses/MV4474.html
	<i>MV 4800 Directed Study in Advanced Modeling, Virtual Environments and Simulation C</i> http://www.movesinstitute.org/courses.html
	<i>MV 4920 Advanced Topics in Advanced Modeling, Virtual Environments and Simulation R</i> http://www.cs.nps.navy.mil/people/faculty/baer/CS4920/webcs4920/Syllabus.html
US North Dakota State University	<i>CS 783: Special Topics/Virtual Environments C</i> http://www.cs.ndsu.nodak.edu/~slator/html/CS783
US Northeastern University	<i>MIM 3142 Building Virtual Environments C</i> http://www1.coe.neu.edu/~mourant/ <i>CSEG 270 Building Virtual Environments C</i> http://www.coe.neu.edu/COE/grad_school/sc_cse_cd.pdf <i>CSEG 280 Human-Computer Interaction R</i> http://www.coe.neu.edu/COE/grad_school/sc_cse_cd.pdf
US Northwestern University	<i>CS 330: Introduction to Design and Analysis of Human-Computer Interaction R</i> http://www.cs.northwestern.edu/~watsonb/teaching/330/index.html
US Ohio State University	<i>ARTS COL 762 Building 3D Virtual Environments C</i> http://www.accad.ohio-state.edu/~pgerstma/class/vnv/
US Old Dominion University	<i>ENMA 725. Virtual Collaborative Environments for Project Engineering R</i> http://web.odu.edu/webroot/orgs/engr/colengineer.nsf/pages/course_descript#ENMA725
US Pennsylvania State University	<i>597D Selected Topics in Interfaces to Virtual Environments C</i> http://www.cse.psu.edu/~rsharma/597/spring97/announce.html
US Purdue University	<i>Tech 519 V Introduction to Virtual Reality C</i> http://www.tech.purdue.edu/cg/courses/Tech519V

Country and University (alphabetical)	Course name and URL (C-Core, R-related fields)
US Rensselaer Polytechnic Institute	<i>CSCI 4966/6965 Parallel and Distributed Simulation Systems R</i> http://www.cs.rpi.edu/~chrisc/COURSES/PADS/FALL-2001
US Rutgers University	<i>14:332:476 Virtual Reality C</i> http://www.caip.rutgers.edu/vrlab/vrclass/ <i>14:332:478 Virtual Reality Laboratory C</i> http://www.caip.rutgers.edu/vrlab/vrclass/recitations/index.html <i>16:332:571 Virtual Reality Technology C</i> http://www.caip.rutgers.edu/vrlab/vrclass/
US Stanford University	<i>377 Topics in Human-Computer Interaction R</i> http://hci.stanford.edu/cs377
US State University of New York at Buffalo	<i>420 3D Virtual Environments Programming Graphics II VR C</i> http://www.ccr.buffalo.edu/anstey/TEACHING/420_S02 <i>MAE 574 Virtual Reality Applications and Research C</i> http://wings.buffalo.edu/courses/sp04/mae/574/
US University of California, Berkeley	<i>CS294 Virtual Reality C</i> http://www.cs.berkeley.edu/~ddgarcia/vr
US University of California, Davis	<i>ECS 280 Principles of Virtual Reality C</i> http://www.cs.ucdavis.edu/courses/exp_course_desc/280.html
US University of California, Irvine	<i>ECE 298 Principles of Virtual Reality C</i> http://maillists.uci.edu/mailman/public/cpcc/2003-January/000008.html
US University of California, Santa Barbara	<i>Creating Multi-person Virtual Environments C</i> http://www.psych.ucsb.edu/~beall/cmve.htm
US University of Central Florida	<i>EIN 525 Interactive Simulation R</i> http://www.graduate.ucf.edu/currentGradCatalog/content/Courses/courses.cfm?Prefix=EIN <i>CAP4021 Building Virtual Worlds C</i> http://www.cs.ucf.edu/~moshell/CAP4021/
US University of Florida	<i>CISE 4390/6390 Design and Creation of Virtual Environments C</i> http://www.cise.ufl.edu/~lok/teaching/dcvf03/syllabus.doc
US University of Kentucky	<i>CS 637 Exploring Virtual Worlds C</i> http://cs.engr.uky.edu/courses/cs637.html
US University of Iowa	<i>056:246 Design of Virtual Environments C</i> http://www.engineering.uiowa.edu/~ie_246/schedule

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US University of Illinois at Chicago	<i>CS 397 WRS Introduction to Virtual Reality C</i> http://www.ncsa.uiuc.edu/VR/cs397wrs/ <i>Eng 490—030, Eng. 591 Virtual Reality Programming C</i> http://www.vrupl.evl.uic.edu <i>DMS 438/553: Virtual Reality C</i> http://resumbrae.com/ub/dms438/syllabus.html <i>EECS 590: Virtual Reality C</i> http://www.evl.uic.edu/aej/590/syllabus.html
US University of Illinois at Urbana Champaign	<i>CS 397 WRS Introduction to Virtual Reality C</i> http://www.ncsa.uiuc.edu/VR/cs397wrs/
US University of Maryland Baltimore County	<i>CMSC 791C Special Topics: Virtual Environments C</i> http://www.csee.umbc.edu/~turner/veF95/policy.html
US University of Michigan-Ann Arbor	<i>Eng 477 Principles of Virtual Reality C</i> http://www-vrl.umich.edu/Eng477
US University of Michigan-Dearborn	<i>ECE 577 Engineering in Virtual World C</i> http://www.engin.umd.umich.edu/~yilu/ECE577_PROJECTS/portell/
US University of North Carolina at Chapel Hill	<i>CS 239 Exploring Virtual Worlds C</i> http://www.cs.unc.edu/~welch/class/comp239/syllabus
US University of North Carolina at Charlotte	<i>Virtual Environments C</i> http://www.cs.uncc.edu/~ifhodes/VE_Course.html
US University of North Texas	<i>CSCI 4330-Designing Virtual Worlds C</i> http://www.cs.unt.edu/~steiner/4330-VR/
US University of the Pacific	<i>COMP193 Interactive Virtual Environments C</i> http://bailey.cs.uop.edu/Doherty/comp193%5CHome.htm
US University of Southern California	<i>CSCI 580 3D Rendering and Computer Graphics R</i> http://www.usc.edu/dept/cs/course_information/580.html
US University of Virginia	<i>CS 551/851 Computer Animation and Virtual Environments R</i> http://www.cs.virginia.edu/~dbrogan/CS551.851.animation.sp.2000
US Virginia Tech	<i>CS 5754 Virtual Environments C</i> http://courses.cs.vt.edu/~cs5754

Country and University (alphabetical) Course name and URL (C-Core, R-related fields)

US University of Washington	<i>ND E 543: Virtual Interface Technology C</i> http://www.hitl.washington.edu/people/TFurness/courses/inde543/SYLLABUS-03/543syllabus2003.rtf <i>ARCH498e Virtual Environments C</i> http://www.hitl.washington.edu/projects/architecture/cedes/arch498e/syllabus.htm
US Wright State University	<i>760 Human Factors Engineering in Virtual Reality R</i> http://www.cs.wright.edu/~jgalli/760HFE00SYL.doc
