Chapter 2

"We should compare the computer not to books, but to a blank sheet of paper, a notepad, an artist's canvas, or a blackboard. The computer may be a tool, but the act of computing itself is a medium for thought"

- B. Hokanson, S. Hooper [10]

Background

This chapter focuses on impact of technology in the education of young learners. In the first section of this chapter, the field of technology in education is explored, introducing research on the use of computers in the classroom and the impact this technology has on educators. It then presents the influence on teaching and learning with computers and introduces the types of software developed for learning. Virtual reality is presented in the second half of this chapter, providing a brief introduction to virtual reality systems. Virtual reality in education is then explored, and the impact it has had on education is discussed in terms of application areas, advantageous attributes and concerns of its use. The chapter then focuses on the approach of virtual laboratories, presenting examples, techniques for evaluating them and major problems encountered with existing virtual laboratories.

2.1 Technology in Education

In a traditional instructional learning environment, students are expected to learn by assimilation, by listening to a lesson presented by a teacher or reading material on that subject matter. Technology provides another medium of learning whereby the computer has achieved groundbreaking results and opened up new avenues for learning. The advent of technology is not a simple exchange of old for new. Technology can change the way children think, what they learn, how they interact and how we assess them [17]. Gaining confidence in their ability to control technology is a valuable lesson children learn from computers [14]. Very young children have shown comfort and confidence in using software that requires single-key presses [17]. They can turn on a computer, follow pictorial direction, and use situational and visual cues to understand and reason about their activity. With changes in hardware, children with physical and emotional disabilities can also use a computer with ease. Besides enhancing their mobility and sense of control, computers can help improve children's self-esteem [17]. Research findings presented in [16] have the following positive findings on computer use in the classroom:

- Students learn more in less time when they receive computer-based instruction.
- Students like their classes more and develop more positive attitudes when their classes include computer-based instruction.
- Students in technology rich environments experienced positive effects on achievement in all major subjects.
- Students in technology rich environments showed increased achievement in preschool through higher education for both regular and special needs children.
- Students' attitudes toward learning and their own self-concept improved consistently when computers were used for instruction.

However, the impact of computers on education due to wide societal use outside the classroom should be considered. Computer use coupled with a societal infatuation with fast-paced, non-linear media in general, may develop a haphazard, hypertext structured thought process, while the traditional educational system is based on reading and writing that fosters the development of a linear, logical thought process that is valued and integrated into the structure of society [10].

Research indicates that as schools and classrooms gain greater access to greater numbers of computers, to more sophisticated software, and to connections to the Internet and the World Wide Web, one of the key issues to be addressed is the need for teachers to become familiar and understand the advantage of the use of such technology. Teachers not only must become familiar with the possibilities for learning and for support promised by these advances but also must help children learn about computers and learn about using computers [6]. This is of utmost importance since busy classroom teachers do not want another instructional tool forced on them without appropriate provisions for training, preparation and implementation [9]. As technology becomes more accessible to early childhood programs, childhood educators have a responsibility to examine its impact on children and prepare themselves to use it for all children's benefit [15].

Without appropriate training, teachers may regard a computer simply as a tool and use it in a limited manner, i.e. only to deliver instruction to students. Such an approach uses only part of the capabilities of a computer (the communicative or representative functions) and fails to acknowledge it's generative potential [10]. One important key to the effectiveness of computer technology is its interactive quality, which allows children to get involved with the content as they manipulate this medium [12]. The manner in which educators use computers is guided by their theoretical understanding of education [10]. Therefore it is essential to give teachers time and support to build confidence and competence in the pedagogy of computer use [11]. Many teacher education programmes are beginning to integrate technology experiences into professional education courses [6]. Teacher education programs should not only teach pre-service teachers how to use hardware and software but also teach them how to incorporate computers into their teaching strategies and activities [6].

There are a number of advantages of incorporating computers into teaching strategies. In the practice of teaching with computers, teachers can take on the role of facilitators or coaches, tailoring their assistance to the needs of individual children [12]. Differences in learning styles are more readily visible at the computer where children have the freedom to follow diverse paths towards the goal. Observing the child at the computer provides teachers with a "window into a child's thinking process". This is particularly valuable with special children, as the computer seems to reveal their hidden strengths [17]. In summary, the use of computers in children's education has great value for children (particularly for those with learning difficulties or for those who are gifted or talented), by serving to [11]:

- Engage children's attention.
- Individualise instruction (a practice of one computer for every child).
- Provide access to learning experiences difficult to provide for by other means.
- Give learners control over their learning.
- Provide opportunities for, and the means of, communication.

2.2 Teaching and Learning with Computers

Computing in education is still in its infancy and has great potential to enrich the learning environment. The role that educational technology plays in the process of education has been addressed by many recent research studies. This section addresses the adaptation of existing learning theories to computer usage, child learning with computers, and pedagogies for educating with computers.

2.2.1 Learning theories

Learning theories embedded in the way children are taught are crucial to successful learning with a computer. Learning theories have been discussed in many research studies. The following is a description of learning principles, theories and concepts commonly used to explain how learning occurs with children.

The general principles of learning presented in [13] are:

- Attention is a prerequisite for learning.
- What is learned persists if it is practised.
- People forget things they do not use.

The research into learning theories and concepts has provided a basis for a pedagogic framework for best practices on using computer technologies. However, to fully account for theories of how children learn is far beyond the scope of this thesis, and for this reason, general principles that apply specifically to learning, when learning is supported by technology, are addressed. Learning theories and concepts used in computer learning include the constructivist paradigm, experiential learning, feedback and reinforcement learning, and incidental learning.

<u>Constructivist paradigm</u>

There is really only one way to learn how to do something and that is to do it. If you want to learn how to tie your shoelaces, you must have a go at doing it. Learning a skill means eventually trying your hand at the skill, and when there is no real harm in simply trying we can allow novices to "give it a shot". This concept is called *learning-by-doing*.

In a constructivist view of learning, the idea is that students are better able to master, retain and generalise new knowledge when they are actively involved in constructing the knowledge through *learning-by-doing* [26].

<u>Experiential learning</u>

Students learn best when they enjoy a rich, often multi-modal, experience of the educational material [13]. Students need to experience concepts and principles contained in the content as much as and as directly as possible. This can be achieved by:

- Increasing intrinsic motivation by giving the learner ownership or control of an experience.

- Achieving mental and physical engagement by appropriate amounts of a challenge and a cohesive narrative framework for the learning experience.
- Learning experiences should be valid within a social context and involve group interaction.

The key distinction to experiential learning is that it addresses the needs and wants of the learner [11].

Feedback and reinforcement learning

Feedback and reinforcement are two of the most pivotal concepts in learning. Feedback involves providing learners with information about their responses whereas reinforcement affects the tendency to make a specific response again. Feedback can be positive, negative or neutral; reinforcement is either positive (increases the response) or negative (decreases the response) [11].

Feedback is almost always considered external while reinforcement can be extrinsic (external) or intrinsic (i.e. generated by the individual). Information processing theories tend to emphasise the importance of feedback to learning since knowledge of results is necessary to correct mistakes and develop new plans. On the other hand, behavioural theories focus on the role of reinforcement in motivating the individual to behave in certain ways. One of the critical variables in both cases is the length of time between the response and the feedback or reinforcement. In general, the more immediate the feedback or reinforcement, the more learning is facilitated. These principles are often used in drill and practice software (see Section 2.3).

Incidental learning

For young learners in particular, play is recognised to be a very powerful learning medium [11]. Not only does play provide a focus for building valuable skills in computer use but it can also provide a means of incidental learning. In particular, playing with computers can be characterised by children building:

- *Intrinsic motivation*. Some software provides for high levels of motivation in learners, where children are motivated by the task presented in the software and undertake a learning experience for its own sake, and often for extended periods of time.
- *Attending to the means rather than the end*. When children are involved in exploring and experimenting with software, they are often doing so in a context where there is no

danger of `being wrong', and are able to build self-esteem and confidence in their abilities to learn successfully.

- *Demonstrating non-literal behaviours*. Role-playing, pretence and imaginative thinking are often hosted in software such as adventure games and simulations.

2.2.2 Learning with computers

By presenting concrete ideas in a symbolic medium, the computer can help bridge the two for young children. Research shows that what is "concrete" for children is not what is "physical", but what is *meaningful*. Computer representations are often more manageable, flexible and extensible. While the experience and opportunities children have using technology are diverse they all share one common thread: each challenges children to explore, discover and learn.

Given the capabilities of a computer, one may ask has it affected children's learning? The effective usage of computer technology may enhance children's learning. Although, some suggest that the initial optimism regarding the benefits of this technology may have been unrealistic. Others criticisms maintain that computers may cognitively de-skill students by eliminating schoolwork that may require mental effort, as the computer now routinely performs many activities once performed in students' minds and consequently the skills previously developed and practised are lost [10]. However, contradictory to the above, computers appeal to a child's imagination and natural curiosity, and capitalising on them can provide many unique opportunities for learning. Young children are eager to learn, willing to take risks, and capable of using a wide variety of learning resources. When children utilise technology, they explore, create, communicate and collaborate with others [12].

In [11], general themes that have emerged from literature that help provide a framework in which information technology, or computers, are best placed to engage learning are:

- *Active learning.* Students learn best when they are actively constructing knowledge by manipulating, creating, experimenting, etc.
- *Personal learning.* Students learn best in a context that they can identify personally with and/or that they own.
- *Individualisation.* Research findings clearly demonstrate that learners each learn differently. Differences in learning can be partly related to cultural influences but can also be accounted for by reference to styles of learning.
- *Gender equality.* It seems that girls are often less likely to make use of computers for a host of social, psychological, and environmental reasons. In this situation, however, there

are well-defined strategies that teachers can implement to support girls' use of information technologies.

- *Cooperative learning.* Cooperative learning is seen as a powerful instructional tool or method, to encourage active engagement by students in learning and to enable learners to build both affective (e.g. team work) and cognitive skills (e.g. articulation). Cooperative learning facilitates group acceptance of common goals, as well as a framework within which to support students to achieve these goals.
- *Learning strategies.* The use of learning strategies is increasingly being recognised as an effective means of producing significant improvements in cognition and motivation to learn.
- *Contextual or situated learning.* Learning is made more meaningful and is acquired more effectively, if situated in real world contexts, rather than in abstract and academic settings. For example, if we wish to learn basic number skills, we are more likely to learn these skills better if they are practised in a familiar and meaningful context, such as buying groceries in a supermarket.

Research studies on the impact of education technology on student achievement presented evidence that learning technology is less effective or ineffective when the learning objectives are unclear and the focus of the technology is diffused [16]. Therefore the way media is used greatly affects its educational potential [10].

There exist links between learning theories, learning with computers and teaching practices. In the next section, the pedagogic applications of computers are presented, which form the links between these topics.

2.2.3 Pedagogies for computers

Do we teach with computers or do students learn with computers?

It is not enough to sit children in front of a computer and let chaos reign supreme. Educators and adults need to guide children, helping them to appropriately use the technology to create, communicate, collaborate and explore. In general, it is the pedagogy that provides for learning in students, not the computer or software alone – without an appropriate pedagogy, computer use cannot provide for any planned, significant learning outcome in students [11]. The computer can offer unique opportunities for learning through exploration, creative problem solving, and self-guided instruction. Effectively integrating technology into a curriculum demands effort, time, commitment and sometimes even a change in one's beliefs [17].

In [11], the following pedagogies are mentioned, which involve the use of one or more computers and associated software, examining theoretical frameworks for education as they guide computer use:

- *Rotational use of computers*. Learners are rotated around a computer in an instructional system where a limited number of computers are situated in a single learning area or classroom. Often this rotation is guided by the use of a roster, controlled by a strict timetable or directly by the teacher, or sometimes with learners themselves determining the length of time they each spend at the computer.
- *The computer station*. A planning strategy used most often in primary schools, where the computer becomes a station alongside a number of other stations (e.g. a reading station, writing station, resource station, painting station). Students might rotate around these stations or perhaps choose a station to work in according to need. This strategy is often practised to make effective use of limited resources, as well as to provide students with choice and decision-making about learning activities.
- *Needs-only basis*. A planning strategy that sees the use of a computer primarily as a support resource in the classroom, and where students are encouraged to use the computer(s) according to need – so, for example, if a student had a need to use the classroom computer as a word processor, he/she would be able to do so; or if another student wished to use the computer as a means of accessing the Internet for locating specific information, he/she would be able to do so. As a planning strategy, deploying one or more classroom computers on a `needs only basis' often leads to a small number of children making exclusive use of the computer (i.e. those with the appropriate skills and confidence).
- *Computer as reward*. The computer has long been used as a reward system for children - perhaps to reward early finishers of `traditional' (i.e. pen and paper) work; or to reward children who complete work beyond their normal standards. In other words, teachers who employ this pedagogy are using the computer as an extrinsic reward, as a motivational strategy; or perhaps as a classroom management strategy.
- *Computer use on contract*. A contract programme is usually initiated as part of a student management strategy, where individual children are presented with contracts of work drawn up by a teacher, each contract describing exactly what an individual student should complete, perhaps in terms of tasks as well as behaviours. These contracts may involve the substantial use of a computer, since computer aided learning (CAL) can provide well for individualised learning. The goal of most contract approaches is to involve students in a negotiation of work, as well as in deciding on the behaviours that should be reinforced

and rewarded as a result of completing the contract. This approach, from the point of view of learning, is intended to provide students with experience of negotiation, self-responsibility and goal setting.

- *Computer as electronic blackboard.* The classroom computer is often employed, at all levels of education, as an electronic blackboard. That is, it is used to demonstrate a concept, event or phenomenon by illustration or description. Different types of software can be used in this context, since the pedagogy for this use of the computer centres on the dominant and mediating role of the teacher in motivating, questioning, explaining to and reinforcing students – the computer is simply employed to demonstrate, illustrate and describe. Perhaps this mode of computer use is best employed when using software that demonstrates a concept; event or phenomenon that is difficult to reproduce by other means.
- *Integrating the computer.* Integration is a concept and pedagogy more common to primary rather than secondary educators. It is based on the notion of employing the use of a computer meaningfully in a number of different curriculum areas or subjects, perhaps in a thematic or topic approach to curriculum design. For example, if an organising theme for a class curriculum is taken to be Fairy Stories, the computer may be used by students to word process a description of a fairy story, take part in a computer based adventure centred on a fairy story, and perhaps develop a `light painting' illustrating aspects of a fairy story using a paint program. There are plenty of ideas for and examples of, computer integration of this sort. In many examples of this approach, the organising theme is taken from a software package itself; very often the software that provides the theme is an adventure or simulation. In other situations, the computer can be integrated almost totally within a set curriculum, without reference to a thematic or topic approach, simply by employing the computer meaningfully and flexibly to both support and extend learning activities. Teachers, due to the difficulties of resource allocation and management, however, rarely attempt this form of integration, as it also demands exceptional planning and integration skills on the part of the teacher.
- *Computer as surrogate teacher.* As a surrogate teacher, the computer is used to set tasks for a student, as well as monitor and evaluate a student's performance in that task. In this sense, the computer carries out a number of roles assumed by a human teacher. Software used for this approach to computer use is often of the drill and practice type.
- *Computer as cognitive tool.* A cognitive tool is usually characterised by a generic item of software, such as a spreadsheet, which provides for knowledge construction and modelling. They are content-free and therefore appropriate to a range of subject or domain areas. Cognitive tools are defined as mental and/or technological devices that

support, guide and extend the thinking processes of their users. Just as a convection oven supports the cooking process, cognitive tools support thinking and learning processes. The computer, in the shape of a cognitive tool, allows the learner to externalise their thinking, to enrich it, manipulate it and change it, all by interacting with one or more conceptual models on the computer. The nature and use of cognitive tools is closely aligned with the concept of cognition as mental models.

- *Role of the teacher*. What role(s) should a teacher play when children are using computer technologies? Well, as with many such 'open' questions, there is not just one answer. Teachers may wish to play a diverse and changeable pattern of roles within or between lessons, just as they might do in a non-computer based teaching context. The roles that a teacher might assume in a computer-based classroom depend on a range of influencing factors, including the type of software in use, the nature and objectives of the learning activities and the instructional strategies employed (e.g. group or individual work). The predominant or 'ideal' role of a teacher when using educational software could be considered a facilitating or guiding one. However, when using some types of instructional software the teacher may be excluded as the computer takes over. It is therefore important to consider how a teacher's role might change in line with different teaching architectures.
- *The computer in a gender equal classroom*. Gender equity is a major issue in computer assisted learning, and various, well-documented findings exist in this area of home and school computer use. For example, there are a well-defined set of teaching strategies that can be implemented to provide for a gender equal classroom in relation to computer use, as well as actions of a more general nature that apply to computer use at both school and home. Indeed, the gender bias of the computer-game market appears to contribute to girls' lack of interest in computer games and inhibits their access to computer technology.

Expanding on the pedagogy of 'integrating the computer', research shows that computer activities yield the best results when coupled with suitable off-computer activities [17]. For example, children who are exposed to developmental software alone show gains in intelligence, non-verbal skills, long-term memory and manual dexterity. Those who also work with supplemental activities, in comparison, gained in all of these areas and in addition also improved their scores in verbal, problem solving and conceptual skills.

2.3 Learning Software

An important question regarding educational computer use continues to be how computers might improve learning. Learning with computers is often referred to as computer-assisted learning (CAL). CAL is directly dependent on the underlying computer software that drives it. Computer aiding software and tools aiding in education have been developed for both individualised instruction and for small groups (mainly due to resource constraints, such as the scarcity of computers). Computer software may carry objectives for learning, where sometimes this may be clear and stated, but often this is implicit and open to interpretation. More explicit objectives in software are usually cognitive in nature and are concerned with students building content knowledge, or perhaps with practising skills with greater accuracy [11]. Software for learning can be pre-developed programmatically or authored using authoring software. How software can be authored or created is discussed next, followed by a classification of the types of computer learning software.

Authoring software

According to Lycos' Tech Glossary [2], an authoring tool, also known as authorware, is a program that helps to develop a multimedia application. Authoring tools usually enable you to create a final application merely by linking together objects, by defining the objects' relationships to each other, and by sequencing them in an appropriate order. Authors with the use of authoring tools can produce attractive and useful graphics applications. Typically, authoring tools require less technical knowledge of the programming domain and most authoring systems also support a scripting language for more sophisticated applications.

An authoring tool that requires little technical know-how would provide a teacher with a simple and quick mechanism to deliver a computer-oriented lesson. However, this depends on the type of authoring tool and the learning objectives. Students can also take on the role of authors. In [16], research of the Learning and Epistemology Group at MIT is presented where they have employed learning by design principles to educational technology by having students (children) become creators and designers of educational software. Here children learn through design activities by programming computers to create applications that other children use and learn from.

Types of learning software

Various types of learning software have been developed for different types of computer learning. Educational software can be characterised not only as a teaching and learning resource, but also as a teaching strategy; that is, a software program carries with it explicit and/or implicit strategies for its use (i.e. instructional strategies) [11]. The types of learning software presented here have been designed to facilitate language development, mathematical skills and higher-order thinking. These are drill and practice software, development software and simulation and discovery-based software.

Drill and practice software has been designed for individual use for practising and improving various skills [12]. This type of software can improve the reading readiness skills of preschoolers and of young learners that show signs of potential reading difficulties. Using this software can also can help young children develop competence in counting and sorting. The gains of using this software are directly linked to the amount of time spent using it [17].

Development software enables children to progress and learn at their own pace [12]. With development software the computer is used as an exploration and creativity tool, and therefore not limited to teaching or learning a particular curriculum [7]. It is important to note that Seymour Papert, a founder of the use of computers in education is the inventor one of the most known development software (Logo). Logo is a procedure-oriented computer programming language developed for young children to 'teach' the computer how to perform tasks and build an understanding of concepts typically related to mathematics [11]. Logo allows the creation of pictures with geometric shapes and children have demonstrated growing knowledge and competence in working with concepts such as symmetry, patterns and spatial order. Research studies on Logo include a study where students have employed Logo in order to design software to teach fractions to younger students [16]. These students were required to structure their computer programs, maintain connections between content and functionality, and design the user interface and activities as well as consider different ideas about how to teach fractions to younger students. This study has indicated that:

- Students who designed fraction software for other students using Logo learned fractions better than students taught fractions using conventional methods.
- Students who used Logo to design software learned Logo better than students who received Logo programming instruction only.

Simulation and discovery-based software is another classification of learning software. A simulation is described as the process of imitating a real phenomenon with a set of mathematical formulas [2]. Advanced computer programs can simulate weather conditions, chemical reactions, atomic reactions, and even biological processes. Simulations can be used as a means of engaging learners in 'learning by doing', or experiential models of learning (see Section 2.2.1). Simulations are also a way of providing goal-based approaches to teaching and learning [11]. Discovery-based software encourages this and allows ample room for free exploration, which is considered more valuable in this regard [17]. In [11], virtual reality is described as an extension of a CAL simulation, where real life can be simulated in such a way that the simulation appears real to the learner experiencing it. Virtual reality is discussed in the next section.

2.4 Virtual Reality

What is virtual reality? Virtual reality is a computer generated synthetic environment that provides the illusion to the user as if it were real. The term virtual reality (VR) is broadly used, and has many definitions and synonyms. Examples of such synonyms are: virtual worlds, virtual environments, cyberspace, synthetic environments, simulator technology and artificial reality. The term virtual reality is sometimes used more generally to refer to any virtual world or virtual environment represented in a computer, even if it is just a text-based or graphical representation [2]. In literature 'virtual world' and 'virtual environment' are often interchangeable. The virtual world is composed of objects that can have geometry, hierarchy, scripts and other attributes. These objects can be positioned and oriented at a location in space (2D or 3D), and by applying translation and rotation operations these attributes can be changed [18].

There are two main types of virtual reality:

- *Non-immersive VR*. In non-immersive VR a standard computer or television monitor is used to display the virtual world.
- *Immersive VR*. In immersive VR, the user is immersed inside the virtual world for a more realistic experience and has been referred to as a technology that literally "envelopes one in a surrogate existence". However this depends on the virtual reality system being used (see Section 2.4.1).

In [18], four key aspects of a virtual reality application are discussed:

- *Input process*. The input processes of a VR application control the devices used to input information into the computer. There is a wide range of possible input devices: keyboard, mouse, trackball, joystick, 3D and 6D position trackers (e.g. glove, wand, head tracker and body suit). Ideally these technologies should provide three measures for position (X, Y, Z) and three measures of orientation (roll, pitch, yaw). Interaction with a VR application involves focussing on the user and examining the style of interaction that can take place between the user and the virtual environment. Interactivity involves moving objects as well as yourself around in the VR environment [4].
- *Simulation process*. The core of a VR application is the simulation system. This is the process that knows about the objects and various inputs. It handles the interactions, the scripted object actions, simulations of physical laws (real or imaginary) and determines the world status. This is basically a discrete process that is iterated once for each time step or frame.

- *Rendering process*. The rendering processes of a VR application create the sensations that are output to the user. There are separate rendering processes for visual, auditory and haptic (touch/force) systems. The *visual rendering process* is most common and has a long history in the world of computer graphics and animations, and is often referred to as the rendering pipeline since a series of sub-processes are invoked to create each frame. A major consideration for graphics rendering is the frame generation rate, which is typically greater than 20 frames per second, as this is the minimum rate at which the human brain will merge a stream of still images and perceive a smooth animation. A VR application is greatly enhanced by the inclusion of an *auditory rendering process*, which may produce mono, stereo or 3D audio. A user's presence is greatly improved by the inclusion of such an audio component. The task of a *haptic rendering process* is the generation of touch and force feedback information.
- *World database.* The storage of information on objects and the world is the major part of the design of a VR application. The primary things that are stored in the world database are the objects that inhabit the world, scripts that describe the actions of those objects or the user (in terms of haptics), lighting, program controls and hardware device support.

The way users see a virtual reality system is referred to as their *perspective* on the virtual world. Because of the flexibility and user control within a virtual environment, the number of possible perspectives a user can find is endless. The ability to use different perspectives, or frames of reference of the virtual world, may be useful for highlighting different patterns and relationships in abstract information. There are two basic kinds of frames of reference: the exocentric and egocentric frames. The first provides the user with a view of a phenomenon or a space from the outside looking in. The latter provides the same view but from within the phenomenon or the space itself. Another view is the bicentric frame of reference, which allows users to alternate between the exocentric and the egocentric frames of reference. By being able to change his/her frame of reference a user will influence mastery in a positive manner, where the egocentric view supports local information while the exocentric view sheds light on information on a larger scale. [34]

2.4.1 Virtual reality systems

In order to understand the use of virtual reality, it is important to understand the technology hardware used to present this medium to the end-user. This section provides a relatively simple description of virtual reality hardware and is intended to describe VR systems that are mentioned in this thesis.

In general, factors shared by most of these emerging and existing technologies are important, such as capabilities, cost, availability, size and performance. These factors can play a major role in assisting educators in selecting affordable and accessible virtual reality hardware for educational purposes, since there are presently very few cost effective technology solutions available. Because of the different types of VR, VR hardware can also be categorised by the type of the immersion that can be provided.

2.4.1.1 Desktop VR

Desktop virtual reality (see Figure 1), a less elaborate computer-created environment is processed on a personal computer and usually experienced on standard CRT monitors. The interaction with the 3D environment is usually done with the aid of a mouse, keyboard and other specialised VR hardware such as a data glove, or spaceball input system. Desktop VR is sometimes called a "Window on a World" (WoW), a window through which one beholds a virtual world [18]. While not very immersive, desktop VR worlds can reflect the textures of the objects portrayed, are interactive and have fully navigable capabilities [4]. This form of VR lacks any feeling of immersion on the part of the user, however stereo modes may be enabled, allowing the user to wear shutter glasses, increasing the 3D perception. Desktop VR is considered the most common and least expensive form of VR, and the most popular platform for educational VR applications, and it is expected to grow in popularity with faster, more-powerful and more affordable desktop computers [9, 26]. There are a number of new fast graphic and video accelerator cards available for the PC, which can deliver cutting edge graphics performance, presenting dynamic, realistic 3D worlds and characters. These cards are referred to as graphics processing units (GPUs) and can now offer a viable alternative to expensive desktop VR systems such as Silicon Graphics workstations.

Figure 1. Desktop VR [20]

2.4.1.2 Immersive VR

Stereo vision that is often included in an immersive VR system, is produced by creating two different images of the world, one for each eye. The images are computed with the viewpoints offset by the equivalent distance between the eyes. There are a large number of technologies for presenting these two images [18].

LCD shutter glasses

Liquid crystal shutter glasses have been designed to shut off alternate eyes in synchronization with a display that sequentially displays the two images computed for stereo vision.

Head mounted display (HMD)

In HMD VR, the user "wears" a stereo display (see Figure 2), much like a pair of glasses that provides a view into the virtual world [21]. The goal in the technology is to provide the widest field of view at the highest quality and with the least weight at a reasonable cost. The main limitation with the technology is that the eyes are covered by the display. New techniques are however addressing this, for example the field of augmented reality (AR) where the computer augments the user's view of the physical world with additional information, by superimposing the physical world onto the computer generated virtual world.

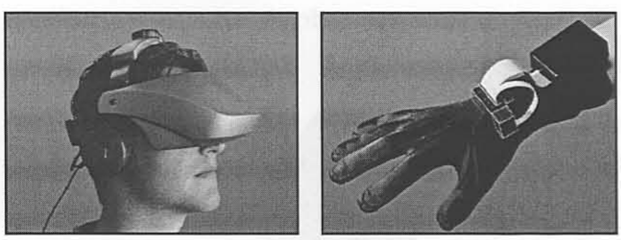

Figure 2. VR products developed by 5DT: The HMD 800 and 5DT Data Glove 5 [22]

Interaction devices

Interaction devices are hardware used as a user's input into the VR system to manipulate or interact with the virtual environment. The simplest control hardware is a conventional mouse, trackball or joystick. While these are two-dimensional devices, creative programming can use them for 6D controls. There are a number of 3D and 6D devices available (called spaceballs) on the market containing extra buttons and balls used to control not just the XY translation of a cursor, but its Z dimension and rotations in all three dimension. Another common interaction media is the instrumented data glove (see Figure 2), which is outfitted with sensors on the fingers, as well as an overall position/orientation tracker. The glove concept has been extended to full body suits with position and bend sensors, used for capturing motion for applications such as character animation. Some interaction devices include a form of force and haptic feedback mechanisms, which are triggered as a result of interaction with the virtual environment. [18]

One of the biggest problems in interaction devices is that of latency in position tracking, the time required to make the measurements and reprocess them before input to the simulation engine [18]. Head and body gear are considered restrictive and uncomfortable [5]. New trends in interaction devices try and eliminate such restrictive media, and include recognition of natural human interaction mechanisms such as gesture and voice.

2.4.1.3 Projection based VR

The following projection based VR systems have been used in the research area of VR in education.

<u>ImmersaDesk™</u>

The ImmersaDesk, was developed at the Electronic Visualization Laboratory at the University of Illinois at Chicago USA, and is manufactured by Fakespace Systems (http://www.fakespacesystems.com), is a 1.27m by 1.7m rear-projected video system with head- and hand-tracking, employing lightweight shutter glasses to present a stereoscopic display (see Figure 3 for an illustration of the ImmersaDesk) [23]. The ImmersaDesk is used in educational VR applications as the display can support a small group of children simultaneously [30].

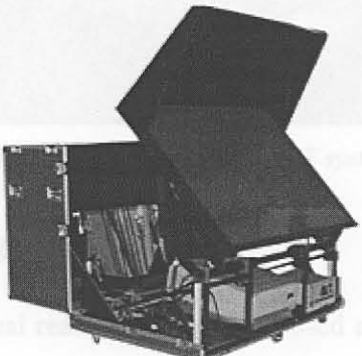

Figure 3. The ImmersiaDesk [19]

<u>CAVE™</u>

In this class of VR, the user functions within a room on which one or more of the surfaces (walls, floor, ceiling) is the display [21]. The CAVE (CAVE Automatic Virtual Environment) was developed at the Electronic Visualization Laboratory, University of Illinois at Chicago, USA (see Figure 4 for an illustration).

The CAVE is a projection-based VR system that surrounds the viewer with 4 screens. The screens are arranged in a cube made up of three rear-projection screens for walls and a down-projection screen for the floor; that is, a projector overhead points to a mirror, which reflects the images onto the floor. A viewer wears stereo shutter glasses and a six-degrees-of-freedom head-tracking device. As the viewer moves inside the CAVE, the correct stereoscopic perspective projections are calculated for each wall. A second sensor and buttons in a wand held by the viewer provide interaction with the virtual environment. [24, 25]. Objects in the virtual scene do not just appear on the CAVE walls and beyond, they can appear to enter into the physical space of the CAVE itself, where the user can interact with them directory [21].

Limited access to systems for research and development resulting from high costs reduces the number and range of potential users [5]. However, with the pace of low-end PC platforms, these systems are now rapidly increasing in numbers and numerous installations exist around the world.

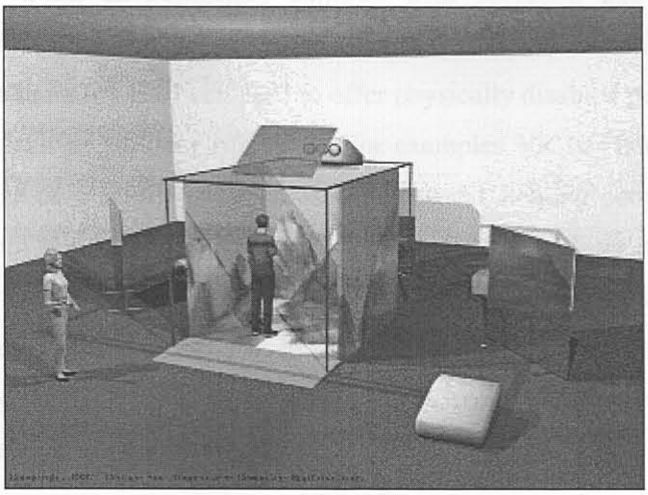

Figure 4. Illustration of the CAVE system [19]

2.5 Virtual Reality in Education

For educational purposes, virtual reality has been proposed as a technological breakthrough that holds the power to facilitate learning. In this section, virtual reality is explored from an educational perspective. The applications of virtual reality in various education subjects are presented, followed by highlighting attributes of virtual reality useful for the pedagogy of, and for learning with virtual reality. The concerns and factors influencing the use of virtual reality in education are then presented.

2.5.1 Educational virtual reality applications

Virtual reality may be used as a means of enhancing, motivating and stimulating students' understanding of certain events, especially those for which the traditional notion of instructional learning have proven inappropriate or difficult. Virtual reality has many applications in various disciplines such as applications designed to for the purposes of training, such as vehicle simulators, medical and military training. In this section however, the applications of VR in the education of young learners is addressed. Virtual reality has been incorporated into many curriculum objectives in the educational domain and the list of educational subjects covered by the use of VR is quite broad. A range of VR applications categorised by educational subjects is presented below, followed by how pedagogic support is embedded in these VR applications.

Special education and life skills

With the use of virtual environments, children with profound and multiple learning difficulties have the chance to access areas of the real world which they might never experience [4]. Virtual reality has been used to offer physically disabled persons the sensation of movement and teach preparatory life skills. For examples VR has been employed in the simulation of the use of a wheelchair in a simulated world, helping people gain experience before venturing into the dangerous real world. With VR technology it is not difficult to imagine a person with a physical disability competing with an able-bodied challenger on even ground in the world of virtual reality [5]. In the training and rehabilitation of young bicycle users, Carnegie Mellon University has developed a Virtual Bicycle projection based VR application, where a user can encounter various accident scenarios [26].

History and world cultures

Exploring of other cultures and ways of living has been achieved using collaborative virtual environments to communicate with other children in other parts of the world. In [4], research on the Vivid Group is presented on a Virtual Cities experiment. A three-way satellite feed system allows children from around the globe to interact with one another in a shared virtual environment. VR environments have also been used to present historical events and ancient cultures. In [36], VR is used to present a cultural heritage application of a once lost Southern African community called Cato Manor, where a user can take on the virtual identity of a young Zulu boy in experiencing the virtual environment. In learning about ancient civilisations, a Desktop VR application of a Greek villa has been developed by Sheffield Hallam University in the United Kingdom for learning about Ancient Greece [26].

Science and Mathematics

VR has been used in exploring chemistry, where three-dimensional models help in understanding the shapes and properties of complex molecules, and in teaching the laws of physics. The effects on physical forces like gravity can be experimented visually, by altering the strength of such forces and therefore creating alternate worlds that violate physical laws of our universe [4]. In [33], three 'ScienceSpace' worlds have been developed for learning complex and abstract scientific concepts: 'NewtonWorld' for learning about Newton's Laws of Motion and the conservation of kinetic energy and linear momentum; 'MaxewellWorld' to explore the nature of electrostatic forces and fields, aiding students to understand the concept of electric flux and discover Gauss' Law; and 'PaulingWorld' for learning about the composition of molecules. In teaching algebraic equations, VR has been employed where students could become parts of the equation, putting pieces of the equation into equilibrium to solve mathematical problems [4].

Biology and Earth Science

The Georgia Institute of Technology, Graphics Visualization and Usability Center has developed a Virtual Gorilla Exhibit which allows a user to explore a representation of a gorilla exhibit at a zoo, in understanding a zoo habitat, gorilla behaviours and social interaction [26]. VR has also been used to teach the 'building blocks' of earth system science, involving the physical, biological and chemical processes, which together make up the earth system [13]. Subjects such as the life cycle of plants and animals in biology, the weather and water cycle, and volcanism and the movement of tectonic plates in geology have been taught with VR applications (see Section 2.5.3.1 for examples thereof). In learning the principles of human cell biology, ERG Engineering, Inc. have developed a Cell Biology VR application for use with a HMD, allowing the user to build cells from different types of organelles [26].

2.5.2 Pedagogies and Learning with Virtual Reality

A number of characteristics of virtual reality hold the potential to enhance the effectiveness of using computers as an educational medium. VR facilitates new kinds of learning experiences that are highly perceptual in nature, and which enable students to be immersed within a phenomenon visually, auditory and haptically. The Virtual Reality and Education Laboratory (VREL) at East Carolina University claim virtual reality has the potential to change the way we learn [9].

Research by Andolesk indicates that virtual reality offers enormous educational possibilities. He says: "Virtual worlds engage students cognitively and affectively and the interactions in these worlds are intuitive. VR is regarded as a highly promising simulation tool, a computer-human interface, a communications medium, and an artistic medium. Applied to instruction, virtual reality has the potential to revolutionize teaching and learning processes. It is for this reason that educators must be aware of this new educational technology" [4]. Dede, Salzman, Loftin and Ash (1999) state: "Our studies are exploring new ideas about the nature of learning based on the unique capabilities that virtual reality provides" [8].

The following highlights a number of attributes and consequences of using virtual reality, which present advantages of using VR as a medium of instruction:

<u>3D</u>

Traditional methods of displaying and visualising models and data are two-dimensional to their nature even through they seek to describe a reality that is often three-dimensional. VR allows students not only to visualise models and data in a more appropriate three-dimensional context, but also to interact with the models and take on several different points of view, changing the models' relative sizes as well as the perspective from which the users experience the models. Virtual reality improves students recognition and manipulation of 3D shapes, improves students motivation and general class performance [26].

<u>Exploring</u>

VR allows for the exploration of real things that, without changes to scale in size and time, could not otherwise be effectively examined, such as molecular structures. Exploring existing places that students would not otherwise have access to, e.g. travel to distant locations, such as the surface of Mars.

<u>Interaction</u>

VR allows for interaction with an environment in non-realistic ways, for example having extraordinary powers and flying around a generated environment [4]. VR also allows for simulating reality for human communication. With a simulated environment, a virtual meeting room can be created with parties interacting together in the virtual room although separated by a great geographical distance. The people present in the meeting can be represented in the virtual environment as virtual characters, also called avatars. Virtual worlds may be constructed to include cues, prompts, reinforces, and feedback delivered through visual, auditory, or even haptic modalities [5].

Understanding

Unique to virtual reality is the ability to make abstract concepts concrete [5]. VR allows for changes in the relative sizes of the user and the objects of the virtual environment. Parameters that cannot normally be seen, such as radiation beams or sound frequencies, can be seen, heard, and even felt in virtual worlds [5]. Representations of abstract concepts like mathematical functions or scientific structures to enable learners to physically interact with them and/or view them from different perspectives, improves learners understanding. Learners may be able to construct mental models of phenomena that have no counterpart in their everyday experience [33]. Virtual reality may be used for creating places and things with altered qualities, such as Earth during an ice age. Exposing students to such experiences trigger insights that lead to a better understanding of the phenomenon as a whole. In [4] it is mentioned that when dealing with abstract concepts through VR simulations, students can develop and retain cognitive skills much easier, hence removing barriers to learning for disadvantaged and gifted students alike.

Economics and safety

In situations where it is too dangerous or expensive to allow students to take on the roles they want to learn, VR can provide realistic experiences through simulations. Simulator training offers invaluable, true-to-life experience without risking the health and safety of the learner or the destruction of expensive equipment [4, 5].

Experience

VR allows for experiences that are not possible in the real world, as it allows for changes in the relative sizes of the user and the objects in the virtual environment. At one extreme, the user could interact with and even step into atoms and electrons, while at the other extreme acquire a sense of distance in the universe by visualising planets and moons. The creation and visualisation of representations of objects and events that have no physical form in the real world are achieved with VR. Virtual reality provides for both individualised and collaborative/cooperative-learning environments, where one can experience communication mechanisms not possible in everyday life. In cognitive science, a whole area of research is striving to enhance collaborative and situated learning [7].

Immersive factor

Immersive VR makes multi-sensory cues to interact with the user, which allows the designer of the virtual environment to use interface designers to present information that is not available to human senses in a direct and clear manner. For instance, variations in the intensity of sound may be used to indicate the current level of radiation, and different places could be given different colours that correspond to the current temperature in that area.

The above list is not at all exhaustive, and there are many more advantages of using VR in education. Dede, Salzman, Loftin and Ash (1999) state: "Our research suggests that such immersive, multi-sensory experiences enhance students' abilities to conceptualise and integrate complex, abstract scientific ideas" [8].

By allowing students to experience various activities in a virtual world, these worlds are intended to help these students learn basic skills that will help in their daily lives [26]. But one may ask what are the pedagogical capabilities of these educational systems? What children can learn from a virtual reality system depends on the extent to which pedagogy is embodied in a virtual world, and the extent of teacher support that is provided.

In [26], pedagogical support in virtual worlds are categorised as the follows pedagogical paradigms which support constructivist learning:

- *No pedagogical support*. This is the simplest type of pedagogy and involves minimal interaction and a simple walkthrough of a virtual world to support the educational objectives. In cases where awareness of VR technology and its possible applications is provided, no pedagogy is needed.
- *Experiential*. With experiential learning, students need to experience the concepts and principles contained in the content as much and as directly as possible. This pedagogy promotes that the learner has control over, or personal involvement in the experience, that there should be an appropriate amount of a challenge for a student, and learning experiences should involve more than just one person, directly or indirectly, establishing group interaction.
- *Guided-inquiry*. In the guided-inquiry paradigm, a student's interaction with the virtual world is guided. Here the pedagogical support is not embedded in the virtual world, but can be provided by other means, for example textual material or a set of questions to be answered about the virtual world.

2.5.2.1 Concerns and factors influencing the use of Virtual Reality in education

The following section presents the concerns and factors influencing the use of VR in education.

The use of VR itself

The attitudes of parents, teachers and children towards computers are a greatly influencing factor of using computers in the classroom and at home. Computer literacy of parents, teachers and school children is an important factor limiting the use of VR in education. Ease of use of the virtual reality application, in terms of both VR hardware and software is another contributing factor.

Pedagogical grounding

Virtual reality technology relies on software applications that do not necessarily have pedagogical grounding [6]. Teachers need to know how to incorporate computers into their teaching strategies and activities in addition to knowing how to use the software [6].

Economics of VR hardware

Should virtual reality be used in situations where it is neither appropriate nor cost-effective? Current VR hardware is expensive and is consequently limited to situations with special funding such as academic institutions and research environments. In a developing country such as South Africa there are hardware constraints in a public school setting. Desktop VR could be a viable alternative.

Ergonomics of VR hardware

Since VR is a relatively new field, the ergonomics of young children using VR has not been addressed. VR hardware has not been designed for use with young children and sometimes shutter glasses are too big, and the devices are too big to fit in the user's hand. Some cases of simulator sickness have also occurred. Also, how a child sits at a computer, in the case of desktop VR, determines whether they avoid eye, shoulder, or back strain [14]. Children need to be advised on such ergonomics, and computer hardware may require investment (e.g. a child may have trouble with an adult sized mouse, where a mouse designed to fit a child's hand will need to be purchased).

2.5.3 Virtual laboratories

Virtual laboratories can be described as virtual environments for educational purposes. Virtual laboratories can be regarded as an extension of CAL software for learning (see Section 2.3). In this section, examples of virtual laboratories in education are presented, including techniques for evaluating virtual laboratories, a guide for the development of a virtual laboratory and the major problems of virtual laboratories.

2.5.3.1 Virtual laboratories in education

In a recent report by the Institute for Defense Analysis, Christine Youngblut has comprehensively surveyed work in virtual environments, citing approximately 50 VR-based learning applications and 35 studies, which include desktop virtual environments [26]. There are currently very few VR-based learning environments designed for young children [32].

Most of these virtual laboratories have been developed for studying the effectiveness of VR on the individual learner, and on whether their use can be successfully aligned with a school's goals, curricula, practices and culture.

The virtual laboratories examples in this section have been presented by looking into the following criteria (where the information has been available or applicable):

- *Pedagogy*. The educational content and pedagogies employed. Educational advantages of the virtual laboratory.
- *Technology*. The VR technology used.
- *Authoring tool*. The virtual laboratory has an authoring tool.
- *Industry Classification*. Has been developed by the research or commercial arena.
- *Classroom*. Has any investigation of the virtual laboratory been conducted on young children in or outside of a classroom environment?
- *Teacher driven*. Teachers' influence in development or a teacher driven system.
- *Collaboration*. Collaborative or individual learning experience.

<u>NICE [26, 29]</u>

NICE (Narrative, Immersive, Constructionist/Collaborative Environments for Learning in Virtual Reality) is a setting for a virtual island where children can search for empty space and build their own ecosystems (see Figure 5). Symbolic representations of various environmental changes are used to facilitate children's understanding of complex ecological interrelationships. Designed to work in the CAVE (see Section 2.4.1.3), and related project-based VR hardware, NICE allows groups of children to learn together in both the same physical location, as well as remotely located sites.

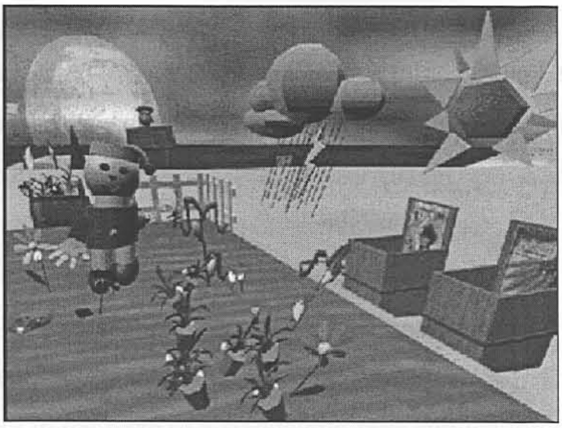

Figure 5. A scene from NICE [29]

QuickWorlds [31]

The QuickWorlds program is intended to provide a fast-turnaround mechanism for teachers who would like to make virtual models available to their students as part of the regular learning program. The models that have been developed range from simple static models such as a wood ant, and the interior of the Earth, to more complicated dynamic models such as the volcano, iceberg, human heart, and solar system (see Figure 6).

The QuickWorlds program has addressed working closely with teachers, as they are responsible for structuring the learning experience and guide the actual lessons using the models. The VR equipment used in QuickWorlds is the ImmersaDesk (see Section 2.4.1.3), which has been installed at the school for the study of how VR may benefit conceptual learning. An example of the pedagogy employed is the use of the heart model by the physical education teacher as reinforcement learning in teaching the function of the human heart.

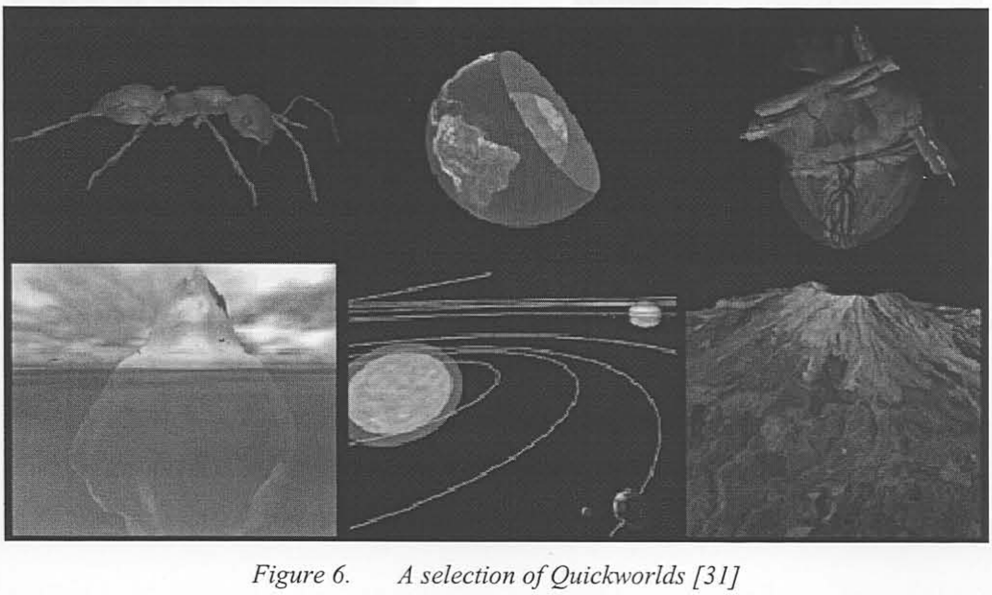

Figure 6. A selection of Quickworlds [31]

First-Person Science Inquiry in Virtual Ambient Environments [30]

Virtual ambients are simulated synthetic environments, which have been designed to support science inquiry learning among elementary school students. Hence users may observe the phenomena in the virtual environment, but cannot affect the course of the underlying simulation.

In a virtual ambient, the Field (see Figure 8), students collaboratively explore a large "natural" terrain populated by up to eight different plant types [30]. The Field is configurable and has an authoring tool in the form of a standalone Java application that allows for selecting a plant type and clicking on the desired location. The system has been implemented on an ImmersaDesk (see Section 2.4.1.3), for the reasons of providing a wide visual field-of-view, supporting collaborative investigations and maximizing the sense of immersion to enhance authenticity (see Figure 7).

The system was tested at a school that places a strong emphasis on environmental awareness. The following is the pedagogic approach used to present sixth grade students to the mathematic concept of co-occurrence using the Field virtual ambient:

- *Scouting*. Writing general observations and taking snapshots of findings.
- *Preliminary discussion*. Presentations of findings from the scouting exercise.
- *Exploration and data collection*. Students take on different roles: navigator, driver, data announcer and data recorder.
- *Follow-up discussion*. Here the teacher teaches the mathematical concept of co-occurrence.

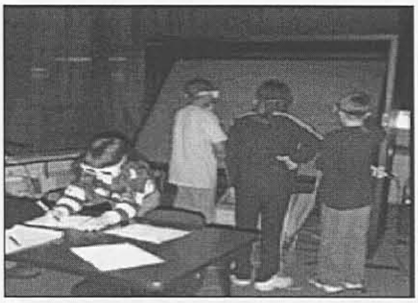

Figure 7. Students interacting with the Field [30]

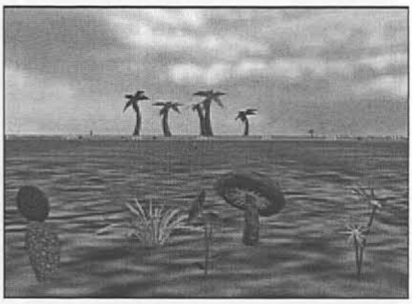

Figure 8. A scene from the Field [30]

Pond-Eco-System Simulator [27]

Argus Virtual Reality International has developed a Pond-Eco-System simulation (see Figure 9). From [27], the following is stated about the simulator: "Here biology is taught through active simulation, where students can interact with their subject. Students can take the role of the different types of life, of flying, swimming or crawling through the virtual environment. Simulated insects operate, as in life, with their own independent goals along with their own pathways".

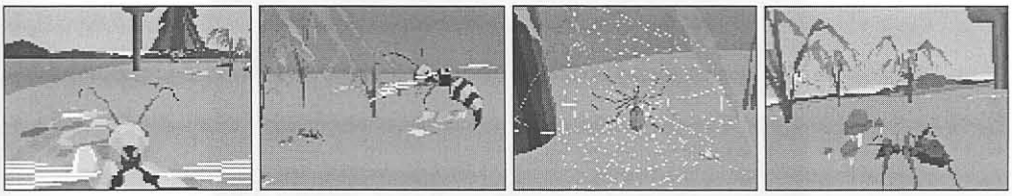

Figure 9. Scenes from the Argus VR Pond-Eco-System simulator [27]

The Round Earth Project [32]

In [32], collaborative virtual reality technologies are used to support pedagogical strategies in teaching children that the Earth is spherical (see Figure 10). This project involved the VR technologies of both an ImmersaDesk and a CAVE system. The pedagogy employed here was the process of children taking on different roles: an astronaut that explores the surface of an asteroid (in a CAVE system), and a mission controller, views and guides the action performed by the astronaut on that same asteroid as seen from an orbital distance (on the ImmersaDesk). Another pedagogy employed was to take control of a spaceship, from the time of lift-off, orbiting the Earth from a distance, and re-surfacing.

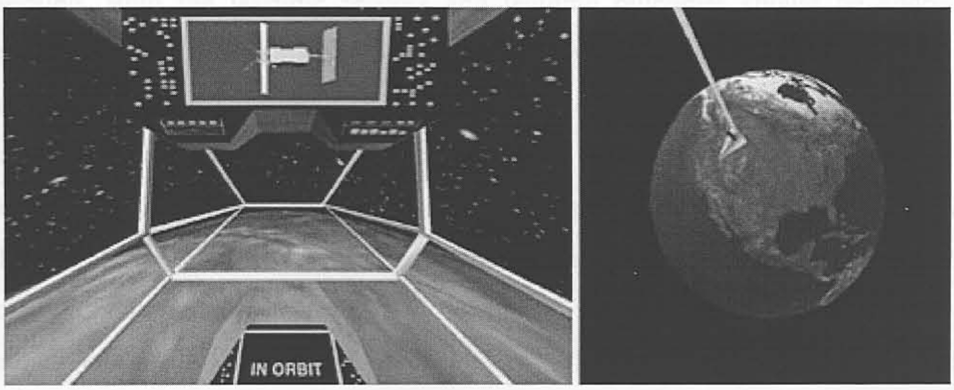

Figure 10. A scene from the Round Earth Project [32]

3D Traffic playground [28]

In [28], a 3D Editor for Traffic Playground was developed, for teaching children traffic rules. In this application, the world is defined by how traffic squares composed of road elements are placed in the editor (see Figure 11). Their orientation and placement directly influence the collision detection model and the flow of movement of traffic within the world. Using the system, it is possible to try basic responses to various traffic situations that are simulated by the system and presented to the user in a simple way.

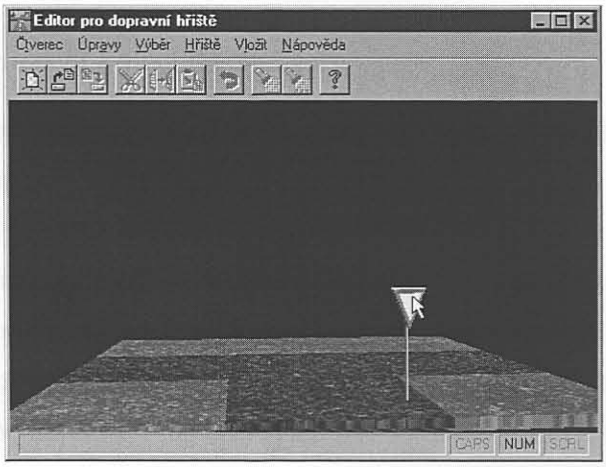

Figure 11. The 3D Editor for Traffic Playground [28]

2.5.3.2 Techniques for evaluating virtual laboratories

Dede, Salzman, Loftin and Ash (1999) [8] have investigated four issues that are critical to evaluating virtual reality worlds:

- *The learning experience*. The VR experience can be characterized along several dimensions. Focus on the participants' subjective judgements of usability, simulator sickness, immersion, meaningfulness of models and representations, and motivation can be addressed.
- *Learning*. Both the learning process and learning outcomes should be addressed in learning. To access learning outcomes, the mastery of concepts at both the "descriptive" and "causal" levels using multiple measures (e.g. conceptual, two-dimensional, and three-dimensional understanding) can be examined.
- *The learning experience versus learning*. It is important to contrast and understand the relationship between the experience and learning and to identify when the VR experiences help or hinder learning.
- *Educational utility*. This contrast centres on whether, for particularly complex and abstract domains, the medium is a better (or worse) teaching tool than other pedagogical approaches. The quality and efficiency of learning among different alternatives of varying cost, instructional design, and teaching strategy should be compared. In particular, learning outcomes should be compared to less-complex technology-based scientific modelling approaches, such as two-dimensional "microworlds".

Pantelidis and Auld of the Virtual Reality and Education Laboratory (VREL) at East Carolina University, US say: "…virtual reality is an instructional tool, one of many that effective instructors use. The choice of an instructional tool depends on the specific lesson objectives, the student(s), and the teacher – the decision to use VR is the instructor's" [9].

2.5.3.3 Development of a virtual laboratory

Any virtual laboratory that is being developed needs contributions from education, from computer scientists and knowledge of the taught domain.

Virtual laboratories may be abstract worlds, or may have been designed to meet specific school curriculum objectives. When developing a virtual laboratory it is important to form technological relationships with elementary students and elementary teachers while working in classrooms. Collaboration with teachers is a necessity. Developers also need to understand the basics of elementary teaching.

The main area of software engineering interested in education is reusability, because of the enormous efforts necessary to develop actually used intelligent systems, and because most efforts in that direction start from scratch [7]. Lelouche states that in using software engineering principles, it is important that there must be techniques and tools to design/develop more cost effective systems [7].

Where will virtual laboratories be in ten years from now? What new and special educational applications will be available to teachers and students? Dede, Salzman, Loftin and Ash (1999) [8] discuss development of virtual laboratories of the future: "Within the next decade, the video game industry will develop devices capable of multisensory immersion ubiquitously available in rich and poor homes, urban and rural areas. To compete with the captivating but mindless types of entertainment that will draw on this power, educators will need beautiful, fantastic, intriguing environments that also foster deep and effective learning". They also say this research will produce another important outcome, "a deeper understanding of human learning".

2.5.3.4 Major problems of virtual laboratories

In realising the factors influencing the use of virtual reality in education and the points discovered in the development of a virtual laboratory, the following list includes major problems involving the implementation of virtual laboratories:

- Not developed on any teaching framework, or do not support the school systems.
- Not developed as re-configurable systems.
- May be very technical.
- Portability on different operating systems is not addressed.
- Most virtual laboratories have been built for expensive virtual reality systems (e.g.: CAVE) which are available only to research institutions or funded research organisations. Immersive educational environments are being developed using high-end equipment. They are consequently limited to situations with special funding such as academic institutions and research environments.
- Developing country issues are not addressed and this educational technology medium has until now only benefited the developed world.
- Not educationally viable and do not address educational needs.
- Virtual laboratories share problems of the concerns and factors influencing the use of virtual reality in education, since they rely on virtual reality as their medium.
- Pedagogy. The relationship between the development and use of new interactive technologies, and traditional pedagogic theory and practice in schools, is becoming somewhat incompatible – is it a case of pedagogy not keeping up with technology; or of technology not delivering what practice and theory in pedagogy demands? [11]

2.6 Summary

In this chapter the field of technology in education was discussed. Technology such as computers and virtual reality were explored from an educational perspective in terms of teaching and learning. The main focus of this thesis in terms of virtual laboratories in education was explored, introducing examples of virtual laboratories and including techniques for evaluating and developing them. The next chapter discusses the theoretical approach that was followed for building the iTiles framework. It presents an approach that can cater for some of the major problems of current virtual laboratories.