An Investigation Into the Viability of Deploying Thin Client Technology to Support Effective Learning in a Disadvantaged, Rural High School Setting.

THESIS

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Abstract

Computer Based Training offers many attractive learning opportunities for high school pupils. Its deployment in economically depressed and educationally marginalized rural schools is extremely uncommon due to the high technology skills and costs involved in its deployment and ongoing maintenance.

This thesis puts forward thin client technology as a potential solution to the needs of education environments of this kind. A functional business case is developed and evaluated in this thesis, based upon a requirements analysis of media delivery in learning, and upon formal cost/performance models and a deployment field trial. Because of the economic constraints of the envisaged deployment area in rural education, an industrial field trial is used, and the aspects of this trial that can be carried over to the rural school situation have been used to assess performance and cost indicators.

Our study finds that thin client technology could be deployed and maintained more cost effectively than conventional fat client solutions in rural schools, that it is capable of supporting the learning elements needed in this deployment area, and that it is able to deliver the predominantly text based applications currently being used in schools. However, we find that technological improvements are needed before future multimedia-intensive applications can be adequately supported.

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List of Abbreviations

CD	Compact Disk
CD-ROM	Compact Disk Read-Only Memory
DVD	Digital Video Disk
ICA	Independent Computing Architecture
ISDN	Integrated Services Digital Network
IT	Information Technology
LAN	Local Area Network
MTBF	Mean Time Between Failures
NOS	Network Operating System
PC	Personal Computer
PSTN	Public Switched Telephone Network
ROI	Return On Investment
TCA	Total Cost of Application Ownership
TCO	Total Cost of Ownership
UPS	Universal Power Supplier
WAN	Wide Area Network
WBT	Windows Based Terminal

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Chapter 1

An overview of the research project

1.1 Introduction

The core function of a school, and any educational institution, is the imparting and acquiring of knowledge. For a long time, the conventional method of teaching and learning in schools has generally been that of a teacher standing in front of the class and disseminating information to the students. How much the students have understood is judged at the end of the year through examinations. In an overpopulated classroom of 45 or more students, as is usually the case in underdeveloped and rural areas, it is difficult for the teacher to ensure that all the students are paying attention and participating in the learning activities in class. This often brings the problem of impassiveness and inattention amongst students, which can lead to failure.

The Eastern Cape region (former Transkei) is regarded as the poorest province in the Republic of South Africa (Eastern Cape Provincial Government, 2001), a situation that can be accredited to the negligence and inequitable policies of the former government of the country. The disadvantages of being a poor province filter through every aspect of life in the region, including the education system. Since education is considered as one of the fundamental building blocks of any country’s well being and advancement, it is easy to conclude that, for as long as the education system in the region is disadvantaged, the region will remain as poor as it is. More than likely, the region will get even poorer if nothing is done to alleviate present educational conditions.

Historically, most of the schools in the region were exposed to a form of education whereby students were ‘spoon-fed’ with information and expected to reproduce this precisely as is, without any thorough understanding of the subject. The shortcomings of such a system become more obvious in tertiary education. It is conceivably hard to transform and cope with the sudden change in education format that is experienced at university and technikon for the pupils from the disadvantaged schools, thereby putting these pupils at a disadvantage when faced with higher learning.

1.2 Problem Domain

This study addresses the possibility of using thin client technology as a cost-effective response to deal with the requirements for interactive, and self-driven learning, in the milieu of disadvantaged Eastern Cape schools in rural and underdeveloped areas. The current educational system in the region has a very limited scope for creativity and interactivity, for both the student and the teacher. There is a need to introduce a new paradigm in the way that education is being approached in the region. This new paradigm has to be a system that will allow the student to engage in a self-controlled and self-paced learning experience. The system also has to stimulate interactivity through participation between the student and the system and between groups of students. A measurement of the student's comprehension is vital to the efficiency of the proposed system; therefore the system has to be able to facilitate assessment and monitoring of student progress.

1.3 Objectives

The primary objective of this study is to investigate and propose a technological solution for the delivery of educational content in an underdeveloped and rural area. The thin client technology has been selected because of claims made in the literature about its cost-effectiveness and reduced complexity. This study is set out to determine whether it would:

a) Meet the educational needs of the proposed deployment area.
b) Be as cost-effective as expected.

Because the envisaged deployment area is poverty-stricken, the cost of the system is to be kept at minimum. At the same time, a certain level of performance has to be maintained if the solution is to work properly and be able to deliver its purpose. It is therefore apparent that a compromise between cost and applicability has to be taken into account in this evaluation.

Scalability will also feature in the evaluation. Technology should be upgradeable and expand in accordance with the users' needs. This project should be able to serve as a reference for the deployment of similar systems in other underdeveloped areas.

1.4 The remainder of the thesis is structured as follows:

Chapter 2: Technology Assisted Education

This chapter is a literature study that investigates the most common technologies that are currently used in the delivery of educational content. The technologies are divided into the computer assisted and non-computer assisted technologies and they are discussed in terms of their advantages and disadvantages. This chapter provides an insight into what can be expected from a range of delivery systems by presenting an overview of the different capabilities of the various technologies.

Chapter 3: Educational Requirements for an Effective Learning Environment

This chapter examines the essential needs that have to be provided to the leaner for an effective learning environment. The essential elements for learning that have been identified are interactivity, control, and richness of media.

Chapter 4: The Thin Client Network Model

In this chapter, the features of the computer network model that is under investigation are outlined. The characteristics that distinguish the computer network model from other computer network models are discussed.

Chapter 5: Costs Analysis

The cost of the proposed delivery technology is highly significant due to the lack of funds in the proposed deployment region. The proposed delivery model is investigated in terms of its cost-efficiency in both the short and long term. The costs incurred in implementing the model are compared with other computer network models that are generally used in the delivery of education.

Chapter 6: Applications Analysis

In this chapter, the ability of the model to meet performance requirements is investigated. Experimental tests of the proposed technology's ability to handle applications that are commonly used in both industry and in education are carried out in an industrial setting.

Chapter 7: Overall Conclusions and Recommendations

Final conclusions on whether the proposed technology is a viable solution for the delivery of education in the proposed deployment region are presented. Opportunities that would be created by the implementation of the solution are outlined, and the shortfalls of the technology are addressed. Guidelines for further research in the field are proposed, and the limitations of this research study are discussed.

The major question to be answered in this research is:

Can a thin client/server network meet the delivery needs of educational content within a rural and underdeveloped area for an effective learning environment in a cost-effective manner?

Chapter 2

Technology Assisted Education

2.1 Context

In order to provide for an effective education in the given socio-economic climate of the target deployment area, as mentioned in the previous chapter, there has to be an investigation into some other means of bringing education to the learners in the area. In this research, technology, and information technology in particular, is proposed as a tool that can bring about a positive change in the educational system of the area in an agreeable manner and at an acceptable pace. This chapter looks at various technologies that are employed in the delivery of education. It has been shown through research that, "students in treatments using media systems consistently scored slightly better than did those in traditional classroom contexts" (Kulik and Cohen, 1979). This finding is for media in general and not one particular media. It is important to note that the discussion about the different delivery media is not to compare them with an intention to find the best media. The goal of media comparison studies is to show alternative means of committing information to long-term memory, as framed under cognitive learning theories (Mayer, 1987).

The purpose of discussing the diverse media is to expose the different media's mode of delivery and their capacity to afford the requirements for an effective learning as discussed in the next chapter. The discussions also help in finding the heuristics for evaluating a delivery media so that they can be applied in assessing the eminence of the proposed system, so as to determine whether it is worse or better than the systems in discussion. Different delivery technologies have different efficacies in the delivery of educational content. The technology chosen for instruction may not affect the eventual achievement outcome, but "it greatly affects the efficiency with which instruction can be delivered" (Winn, 1990).

The different technologies are also discussed in their ascending order of complexity in order to observe the proportion between their capabilities and their complexity. Different media prompt different stimuli from the learner, e.g. printed material can only be read and not heard, whereas radio programs can only be heard and not read. The consequences of different stimuli and their benefits for effective learning are presented in the next chapter.

2.2 An overview of alternative means of education delivery.

Alternative means of education delivery are unconventional methods of delivering educational content to the learner. The conventional way is that of a teacher standing in front of the classroom and disseminating information to the learners. Alternative methods are mostly technology assisted and they have mostly been used in distance education where it is not possible for the teacher to stand in front of all the learners. They can however, be applied to the conventional methods of learning in class. In this chapter all of the technology assisted learning environments apply for both distance education and classroom based learning.

> *Distance education ought to be regarded as education at a distance. All of what constitutes the process of education when teacher and student are able to meet face-to-face also constitutes the process of education when teacher and student are physically separated* (Shale, 1990).

"Distance education is a concept that covers the learning-teaching activities in the cognitive and/or psycho-motor and affective domains of an individual learner and a supporting organization. It is characterized by non-contiguous communication and can be carried out anywhere and at any time" (Holmberg, 1989).

Holmberg's definition of distance education suggests, amongst other things, that distance education is aimed at the individual learner's intellect and emotions, and can be performed anywhere at any time. The University of Wisconsin's Distance Education subgroup defines distance education as a planned teaching/learning experience that uses a wide spectrum of technologies to reach learners at a distance and is designed to encourage learner interaction and certification of learning (University of Wisconsin-Extension, 1998).

Traditionally, distance education has been correspondence or home study where the student-teacher relationship is through postal mail. Nowadays, more sophisticated technologies are used as delivery media. This does not come as a surprise for the reason that, “it would be hard to find any industry whose vision of the future has not been changed radically by the dawn of the Internet Age” (Farrington, 1999). The effects of technology are evident in almost all spheres of life, and delivery of education is no exception.

It is imperative to look at the various technologies that enable the delivery of education to learners.

> *Distance education is inexorably linked to the technology of delivery. It can be seen as a set of instructional methods based largely on mediated communication capable of extending the influence of the educator beyond the formal instructional setting for the purpose of benefiting the learner through appropriate guidance and support. Without technology, a future for distance education does not exist* (Garrison, 1990).

Most of the new technologies that are used for the delivery of education in general and distance education are computer assisted in one way or another. This is an advantage for the users of the technology, because the exposure to computer-assisted technology naturally promotes computer literacy. For the sake of simplicity, the technologies for the delivery of education will be divided into two main categories; i.e. computer assisted, and non-computer assisted.

2.3 Non-computer assisted learning

This category of education delivery technologies does not depend on computers for its function, but instead it relies on unsophisticated technologies and appliances that are readily available. The most popular of these are the following:

2.3.1 Print

Printed material is the most basic and the oldest form of education delivery from which other delivery modes have evolved. Garrison refers to printed material as " the first generation distance education technology" (Garrison, 1990). Mail correspondence is the most widely used method of distance learning, particularly in third world countries, due to the low costs incurred.

> *Currently, many distance education institutions in developing countries use print-based correspondence study as the main distance education medium, as the use of communications technologies is often cost prohibitive* (McIsaac and Gunawardena, 1996).

The learner is not required to learn any superfluous skills in order to use this technology, because all high school going children are able to read. The teacher communicates with the student through assignments, notes, study guides, and tests that are supplied to the students.

> *The difficulty with correspondence education has been the infrequent and inefficient form of communication between the instructor and the students. Also, it was difficult to arrange for interaction in correspondence-based distance education* (McIsaac and Gunawardena, 1996).

Correspondence of printed material emphasizes learner independence. It has a long history of success stories to its credit and is still in operation to this day. The advantages and disadvantages of this delivery system are:

Advantages:

- Printed material is cheap to produce and can be used anywhere, anytime without the need for sophisticated technology. This makes it very suitable for underdeveloped areas.
- High school learners are able to read, therefore there are no extra skills that are required to learn from printed material. Unlike other sophisticated technologies, most people do not feel intimidated by printed material. This enables the learner to concentrate more on the content of the subject than on the delivery system.
- Compared to other delivery mediums, printed material is a more transparent medium to the learner. Even in the traditional classroom scenario, the teacher can distract learners from paying attention for various reasons e.g. the color coordination of the teacher’s clothes, the teacher’s accent and intonation, and so on. This leads the learner to lose focus and their mind to digress from the lesson. Printed material is very transparent in the sense that there is less to mesmerize the learner and distract his attention.
- Printed material is easily referenced and can be reviewed instantly by the learner at any time. This helps the learner to go back and review only the parts that the learner needs to, without wasting time on material that is understood or unnecessary.
- Printed material is very portable and can be easily carried to any place.
- The low cost of printed material makes postal correspondence an affordable way to learn at a distance.

Disadvantages

- The main disadvantage of this delivery medium is that it lacks effective interactivity. When used in distance education, the teacher and the learner cannot see or hear each other, and the only way that they can discuss an issue is through postal mail. The time involved in this type of interaction is too long and too inconvenient.
- The understanding, motivation and the grasp of concepts are mostly entirely left to the learner's abilities. Since this delivery medium relies on the written word, it is limited to the content it can cover. For an example, printed material is inadequate for learning a language, where the learner has to hear the pronunciation of words. A test through diction, which is essential in this field, would be impossible.
- This delivery medium lacks emotion. Emotions are significant in the emphasis of certain aspects during learning, e.g. change in tone to emphasize an important point.

2.3.2 Radio

Radio has been used as a communication tool for a long time. Educational radio began at the University of Iowa in 1911 (Wolcott, 1993). Educational content is still aired over the radio in many nations of the world.

It uses inexpensive and readily available technology of a radio waves i.e. short wave, medium wave and frequency modulation, and has the capability to cover long distances and reach a large audience. At the receiver's end, the listener only needs a radio receiver, which is an inexpensive device that is available in a lot of households even in poor communities.

> *In summary, as with other media, radio has been found to be at least as effective as conventional instruction, although the literature is limited* (Tripp and Roby, 1996).

Advantages

- The instructor can reach a wide audience, spread over a large geographical area at once. Unlike print, a group of learners can listen to one program all at once, whereas it is impossible for a group of learners to read one book at the same time. This is beneficial to those who might not have a radio receiver in their homes, because the technology can be shared at no extra cost.
- This delivery medium has the option to be used in conjunction with printed material.
- It is an inexpensive delivery medium that utilizes something that most households already have.
- Since most people are familiar with the radio, the technology does not intimidate learners.
- It is a portable medium that can be used anywhere with very little effort.

Disadvantages

- This medium of instruction is passive in nature, and like printed material it provides no interaction between the learner and the teacher.
- Because it is a synchronous communication, the material covered cannot be referenced or reviewed instantly. If the learner has missed out on something it is impossible to review what has been missed unless a device such as a recorder is used.
- The content covered is limited to that which can be covered orally. Visual material and demonstrations are impossible in this medium.
- It is impersonal in the sense that it does not cater for body language like smiles and frowns.

2.3.3 Audio Teleconferencing

Audio teleconferencing or audioconferencing is a full duplex, voice-only communications medium whereby two or more parties at different locations are connected via the Public Switched Telephone Network (PSTN). The teacher and the students communicate through telephone lines in real time. Students are able to interrupt and make comments or ask questions at any time for as long as they are connected. This brings a new level of interactivity in comparison with print and radio.

> *Even though it lacks a visual dimension, audio teleconferencing has some major strengths: It uses the regular telephone system, which is readily available and a familiar technology; it can connect a large number of locations for a conference; the conferences can be set up at short notice; and it is relatively inexpensive to use when compared with other technologies* (McIsaac & Gunawardena, 1996).

The equipment necessary to establish an audioconferencing session depends on the number of locations involved, but nevertheless should include telephone lines, speakers, microphones, and an audio bridge in the case of multiple locations being connected at the same time.

Advantages

- Audioconferencing is a synchronous full duplex communication therefore students have the ability to communicate and interact with the teacher anytime during the lesson in real time.
- The medium has the ability to reach a large audience that is spread over a large geographical area, all at the same time.
- Students in different locations can interact with each other and the teacher as well.
- This technology requires a basic telephone line, which is not very expensive to install. A lot of schools, even in rural areas, already have a basic telephone line nowadays.

- Once an audioconferencing system is installed, it is very easy to operate and requires no specialized knowledge for its operation. This eliminates the frustration and intimidation that comes with more sophisticated equipment. The learners get to concentrate more in the content of the lesson than in the technology itself.
- The medium can be more effectively used in conjunction with printed material.

Disadvantages

- This system, like the ones mentioned before, still lacks emotion in the sense that body language is not represented during the lesson.
- The subject content is limited to that which can only be communicated orally.
- The system uses the Public Switched Telephone Network (PSTN) and for the students to keep track, the connection must be maintained for the duration of the lesson. This could be problematic for a rural area where the quality of service of the telecommunications provider is not as good as it is in the urban areas. A connection can be lost and there would be a need to redial. This would increase the time spent on the lesson and inevitably increase the cost of connection for every party involved.

2.3.4 Television

Television is a familiar communications technology that has gained popularity throughout the world, including poor communities. Synchronized video and audio signals are transmitted from a broadcast station, received by an antenna and reappear as a motion picture on the cathode-ray tube in the television set at the receiver’s end. In urban areas television has become so pervasive that most of the people in the cities take it for granted just like electricity. Even those who do not have a television set in the rural areas are informed of its existence. Almost all high school going pupils have been exposed to television at one time or another. Television is particularly an exciting media in the poor communities, and people in these communities are very enthusiastic about watching television.

> *Contrary to high socioeconomic-status children who demonstrate a negative correlation, low socioeconomic-status children can improve achievement with television viewing* (Anderson et al., 1986).

Education benefits immensely in using television as a delivery medium. In South Africa the South African Broadcasting Corporation (SABC) has been successfully airing educational material aimed at high school pupils through a program called *The Learning Channel*.

Some researchers have criticized television in that its images and associated presentation effects are cognitively debilitating. This is hypothesized to result in cognitive passivity, shortened attention spans, and hyperactive behavior (Winn, 1977).

> *The central assertion of this viewpoint is that the rapidly changing television image enhanced by production features such as cuts, zooms, animation, and special effects-is cognitively mesmerizing* (Seels et al., 1996).

Television is a simplex synchronous medium; therefore it lacks interaction between teacher and learner, and between the technology and the learner.

> *Broadcasts are ephemeral, cannot be reviewed, are uninterruptible, and are presented at the same pace for all students. A student cannot reflect on an idea or pursue a line of thought during a fast-paced program without losing the thread of the program itself. A student cannot go over the same material several times until it is understood* (Bates, 1984).

This suggests that television viewing assumes the same pace of learning for all students, which is not necessarily true. Bates also argues that, “most students find it impossible to take notes while viewing, and those that do are usually very dissatisfied with their notes” (Bates, 1983).

Advantages

- This media provides the combination of audio and video to provide multimedia content for the student. Studies have shown that the more senses that are involved in a learning experience, the better it is for the learner to apprehend and recall the lesson.
- Emotions and body language can be visualized by the learner so as to get a better insight into what the teacher is saying.
- The television has the ability to bring visuals of abstract ideas that the learner would otherwise never be able to visualize. Television can display a motion picture about the undersea world, or the planet Mars, or even through the lens of a microscope, something that would not be possible with other media that have been discussed above.
- It is a very familiar technology, and would not intimidate the learner.
- Information and world events can be relayed to the student as they happen.
- A very large group of learners can watch the same program at the same time.
- It would be unlikely for learners to get bored, since most school going pupils in low socioeconomic status like to watch television (Anderson et al., 1986).

Disadvantages

- The total costs incurred makes television an expensive medium for delivering education.
- Since it is a simplex synchronous system, interactivity is limited and can only exist if the medium is used in parallel to other media such as audioconferencing. This would yield even a higher price for the complete system.
- All students receive information and are expected to process it at the same pace, and therefore the student has no control at the pace of absorbing the information.

2.4 Computer assisted learning

Computers have affected all of modern life in a variety of ways, particularly in the way that people communicate. The computer is probably the most versatile tool that human beings have created in the 20th century, and its use will keep on affecting human life well into the foreseeable future. Computers have become a vital part of the tertiary curriculum, and understandably so. There is not a single type of work that does not make use of computers nowadays.

> *Today, business, law, engineering, science, art, journalism, academics, as well as a whole host of other professions and occupations all require a basic understanding of, as well as the ability to work with, information technology… Regardless of students' major in college, or intended occupations in the future, information technology will play an integral role in their success* (Laudon et al., 1996, 2000).

In developed countries tertiary students, no matter which faculty they are registered in, must learn the basics of computing through introductory courses like computer literacy and word processing. This compulsory training in computing is available at high school level, and even earlier in the developed countries.

Education, as a whole, is benefiting from the use of computers through various forms of technologies that aid the delivery of education. Figure 2.1 presents a flow chart diagram of computer-assisted instruction. Except for the delivery of content, one of the tasks that are performed by the computer is the remediation of incorrect responses. This is the step where the computer provides feedback that coaches the student to repeat the exercise and rectify where the student has gone wrong. Tools like artificial intelligence make it possible for the computer to analyze the mistakes made so as to find out the exact weakness of the learner so that only the learner's misunderstanding is rectified.

Computers enhance teaching even in the orthodox setting of the classroom by means of computer presentations. Students tend to pay more attention to multimedia presentations, because they are more pleasing to the eye than the ordinary chalk and blackboard, and they may contain audio or video as well. Nowadays the computer technology is combined with telecommunications network to provide distance education to the remote learner. Some of the common forms of computer-aided delivery methods are discussed next.

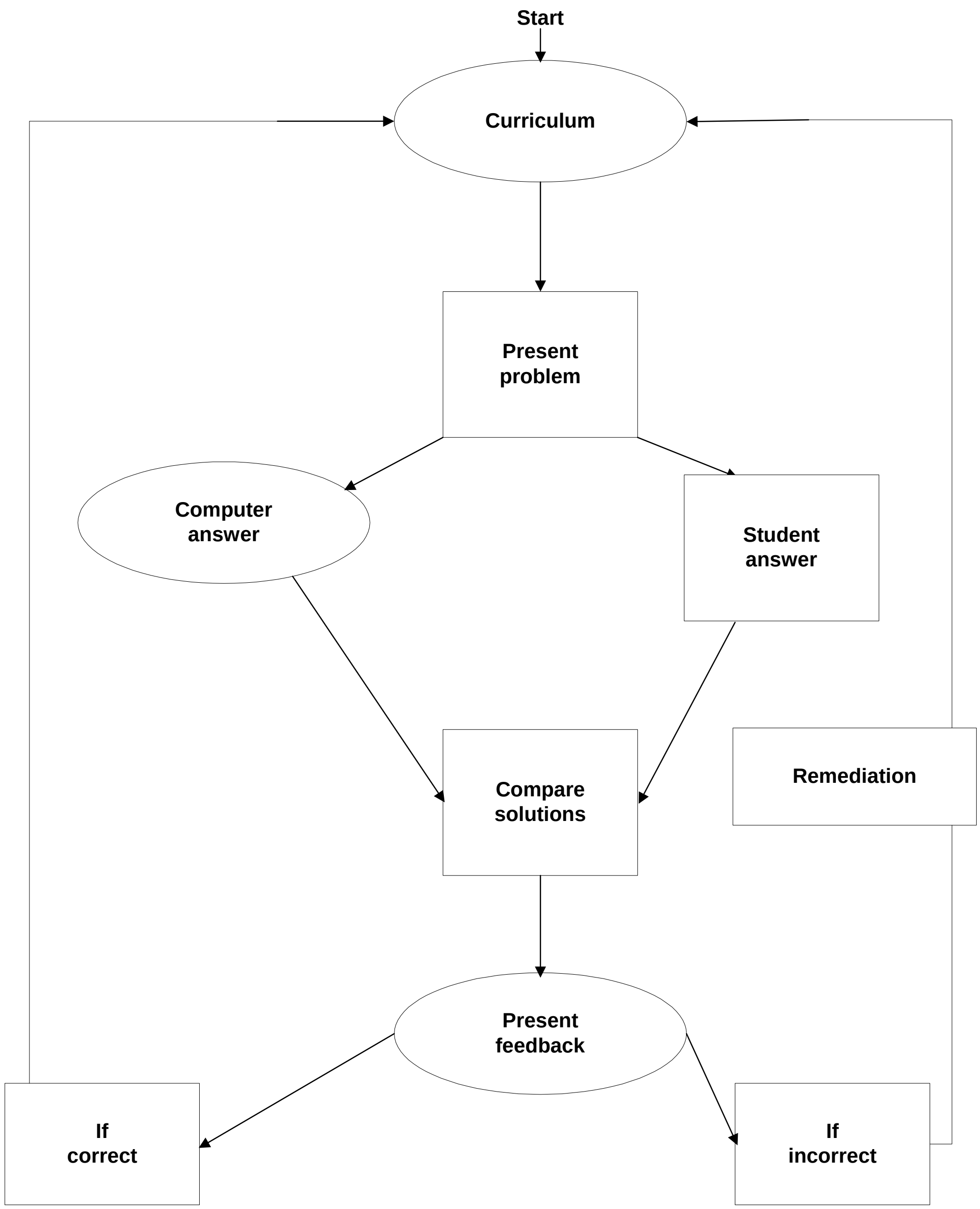

Figure 2.1 Computer assisted instruction (Shute & Pstoka, 1996).

2.4.1 Stand-alone computers

Standalones are personal computers (PCs) that are not connected to a network and operating as discrete units. All the information that is being accessed is from one of the computer's storage devices. A computer is a multimedia tool and therefore has the capability to deliver media rich content to the learner. The 600 MB capacity of the CD-ROM and the low price of the CD recording media has made the CD-ROM a very popular information distribution media.

> *CD-ROM is one of the most promising of the rapidly emerging technologies for education. An ever-increasing amount of text, graphic, and even full-motion video data is being recorded and distributed on CD-ROM. There is also a constantly expanding hardware base for CD-ROM as more and more personal computers are being shipped with CD-ROM drives and people are retrofitting PCs with the drives* (McIsaac and Gunawardena, 1996).

The learner can interact with the device and search for a topic by entering a search phrase and the subject will be displayed almost immediately. Nowadays PCs can be shipped with Digital Video Disk players (DVD), which stores more information than a CD-ROM disk.

A stand-alone PC and the user interact at a user-defined pace, enabling the learner to ingest and process information at an individual pace. The user has full control on how much information and what type of content they need to access. Since a stand-alone is not connected to any computer network, interactivity is only limited between the user and the technology.

Advantages:

- Computers can facilitate self-paced learning because the learner has total control over the flow of information.

- Computers also facilitate individualized learning because each individual learner has the ability to access only what they need.
- Computers are multimedia tools and they provide the learner with media rich content with pictures, text, data, sound, and video.
- Since the interaction between the student and the technology is user-defined, the material can be easily referenced at any time, and the learner can go through it for as many times as they wish.

Disadvantages:

- The technology in computers changes so rapidly that it would be hard for a poor community to keep up with the upgrades in software and hardware.
- The maintenance of the equipment is costly, and adds a considerable amount to the total cost of ownership.
- Learners need to learn the basic skills of operating a computer before they can be able to use it for educational purposes. Since it is an unfamiliar technology to most rural people, the user might be intimidated by the intricacy of operating a computer.

2.4.2 Video teleconferencing

Video teleconferencing or videoconferencing is full-duplex synchronous interactive telecommunications technology that transmits video and audio signals over data lines between two or more locations. It is mostly used in conjunction with sophisticated computer equipment that controls and places effects such as audio and text on the viewer's screen. Videoconferencing is popular in distance education because of the high level of interactivity that it offers. The teacher can see and hear the students and the students are also able to see and hear the teacher in real time. This is in effect very close to the traditional in-class scenario.

> *Because of its ability to show the images of people, video teleconferences can create a "social presence" that closely approximates face-to-face interaction* (McIsaac and Gunawardena, 1996).

A videoconferencing session can be held between two locations, which is point-to-point; or between more than two places, which is point-to-multipoint. The expenses incurred are proportional to the number of sites involved in the session. The participants at various locations can dial-up the main hub using the Integrated Services Digital Network (ISDN) or can be connected via dedicated lines.

Advantages

- The ability to involve many students at different locations is an advantage for this technology.
- Since it is a multimedia technology, many types of media are involved in making up the lesson.
- Since videoconferencing is a synchronous connection, everything in the lesson is in real time, and this allows a continuous interactivity between the teacher and the students. The traditional in-class teaching is best simulated in this type of delivery medium.
- It has the ability to be used in conjunction with other media such as printed material.
- Experts on certain fields can be invited to talk about a subject of expertise to a large audience all at one time, thus avoiding the time and costs of transport.

Disadvantages

- The costs involved both in the hardware investment and the costs of the communication itself are very high. For a quality connection between participants, more than one communication line is necessary to connect the participants. This is done in order to increase the bandwidth of the connection so that more data can be transmitted.

- This system inherits some of the problems of in-class teaching. Students may still be apathetic about the lesson and neglect to participate in the class discussions.
- For the session to be effective, a connection between the participating parties must be maintained throughout the session. This is almost impossible in rural areas where the quality of service of the telecommunications providers is not up to standard and the rate of failure is high. A bad connection may result in jerky pictures or distorted audio and a total disconnection at worst.
- The connection is synchronous, which means that the students will not be able to review the lesson content later on. The pace of the lesson is entirely dependent on the teacher and all the learners have to learn at the same rate.

2.4.3 Networked computers

Networked computers are PCs that are connected together by a computer network, so that they can share services and files. In most network architectures the storage and processing of information is distributed over the entire network and not in one centralized location as in the case of stand-alone computers. Many architectural designs are possible in the design of a network depending on the function and the monetary constraints of the network. The most popular of these architectures is the client/server architecture and it is the most widely deployed architecture in networked computers.

Networked computers have all the advantages of stand-alone computers with the added benefit of being able to communicate with other computers on the network. This creates the ability for students to interact with the teacher and each other and brings an improved level of interactivity compared to stand-alone computers. Networked computers also provide the possibility for students to work in groups through collaborative learning.

> *The students can be divided into groups and the members of a group can be assigned different roles. Tasks (homework or exercises) can be divided into subtasks that can be assigned to group members with different roles to tackle. Concepts can be discussed from different perspectives by each member with*

his/her specific role. The learning effect can be improved because the students can observe and learn things from different views. Additionally, students can be motivated through group and peer pressure and may be more willing to cooperate, exchange ideas, and share experiences in order to get a good score for their group activity (Bricker et al., 1995).

In networked computers, the interaction through workgroups can be implemented beyond the borders of the classroom with students from different schools and grades collaborating on a project through the computer network.

Advantages:

- As in the case of stand alone PCs, the learner has the control over the flow of information in networked computers.
- Networked computers also provide the possibility of the learner to work individually or as part of a work group study.
- Interaction between student-teacher, student-student, and student-technology is possible through this technology
- Networked computers provide for multimedia rich educational content with pictures, audio, text, and video.

Disadvantages:

- Computer networks are expensive to implement because of the cost of acquisition and highly skilled labour involved.
- Network availability is critical because failure for the network to operate would affect the progress of the whole class.
- In most present day network architectures, the maintenance and administration of the network is costly, and adds a considerable amount to the total cost of ownership.

- Learners need to learn the skills needed to operate a computer before they can be able to use it for educational purposes. This may intimidate some users who are not unfamiliar with computers.

	Cost	**Portability**	**Interactivity**	**Level of Skills Required**	**Time-liness**	**Multimedia**	**Reach**	**Mode**	**Intimidation**
Print	Low	Yes	No	No skills required	Instantly	None	Few	Asynchronous	None
Radio	Low	Yes	No	No skills Required	Delayed	None	Many	Synchronous	None
Audio Teleconferencing	Low	No	Yes	No skills Required	Delayed	None	Many	Synchronous	None
Television	High	No	No	No skills Required	Delayed	Yes	Many	Synchronous	None
Stand-alone computer	High	No	Yes	Operating skills required	Instantly	Yes	Few	Asynchronous	Yes
Video Telecon-ferencing	High	No	Yes	No skills Required	Delayed	Yes	Many	Synchronous	None
Network Computers	High	No	Yes	Operating skills required	Instantly	Yes	Many	Both	Yes

Table 2.1 Comparisons of different delivery technologies

Table 2.1 compares the different delivery technologies that have been discussed in this chapter according to the different features that they have, which can be described as follows:

- The costs are the relative monetary expenditures that are incurred when the technology is deployed for the delivery of education. These costs include the cost of acquisition and the general support and maintenance costs.

- Portability is the ability to carry or move the technology from one location to another.
- Interactivity is the ability of the technology to offer collaborative interaction between the teacher and the learner or between the technology and the learner or amongst learners themselves.
- Level of skill required is the expertise that is required in order for the learner to operate the technology during lesson time.
- Timeliness is the amount of time that elapses before the learner is able to review the material that has been presented through the technology. The material can either be instantly reviewed or the reviewing can be delayed. Instantly reviewed material occurs when the learner is able to go over the material as soon as they want to as in the case of books in printed material. Delayed review happens when the learner has to wait for some time before they can be able to revise the learning material again as in television.
- Multimedia is the technology’s ability to present integrated information in more than one form such as text, images, video, and sound.
- Reach is the number of learners that can be reached at once using the technology.
- The mode differentiates whether the technology operates in a synchronous or asynchronous mode.
- Intimidation is the anxiety level that the learners experience when using the technology. If the learners are faced with an unfamiliar technology, they will be more anxious to use the technology than when using a familiar technology. Also, if the technology requires its interface to be learnt before the learner can use it, then the learners will be more intimidated by the technology.

2.5 Conclusion

The range of technologies that support the delivery of educational content, and that are outlined in this chapter, have been discussed from the users’ point of view, so as to show how the user interacts with the technology. The technologies offer various ways of delivering educational content to the learner, and they have different characteristics in the way that the user interfaces with them. The purpose of the discussion is to provide a general overview of the characteristics of the broad range of technologies that are available in educational delivery. Their advantages and disadvantages have been detailed so as to provide an overall understanding of the strengths and the shortfalls of each technology. This understanding provides an insight into what to expect from an educational content delivery system and the things to avoid in such a system. The ideal is to incorporate all the advantages of each system and prevent all the disadvantages in the system that is proposed in this research study. The technologies discussed in this chapter also differ in the way they interact with the learner. How this affects the understanding and retention of educational content is discussed in the next chapter.

Chapter 3

Educational Requirements for an Effective Learning Environment

3.1 Context

In the previous chapter, different delivery modes for learning were discussed so as to understand their characteristics in terms of their advantages and disadvantages. The aim of investigating the characteristics of these technologies is to make sure that the desired solution avoids the disadvantages whilst employing as much of the advantages as possible. The investigation of advantages and disadvantages is carried out so as to provide a generic view of the different aspects of diverse educational content delivery systems. In this research the learner is assumed to be the center of the learning environment and therefore the needs that enable the learner to gain access to a favourable learning environment are a priority. This chapter investigates the necessary elements that are required in order to provide for a favourable and conducive learning environment.

It is very important to take the user's requirements into consideration because, "whereas designers (of educational content) have traditionally focused on what subject matter to teach and how best to teach it (e.g., presentation and sequencing strategies), emerging learning systems place greater responsibility on the learner (Hannafan et al., 1996). For the purpose of this research project, the users are more importantly the students and less importantly the teachers.

As it has been mentioned in the introductory chapter, the particular users in the envisaged deployment area have unique needs that can be attributed to their political and social environments, past and present. The objective of this project, as previously mentioned, is to propose and investigate a means of providing low cost and effective learning experience to the users in a rural and underdeveloped environment. To accomplish this the present educational system in the targeted deployment area has to be looked at, and its flaws and inadequacies that make it an inferior educational system must be examined. From that we can be able to ascertain how can these flaws be addressed by the proposed system of delivery.

3.2 Necessary elements of learning

The present scenario in the envisaged deployment domain is that of an inferior education, which is provided to the learners based on how well a learner can remember what they have been told in class or instructed to read from textbooks. Students are expected to memorize the subject content without thorough understanding of the content. Those who earn more than a preset minimum mark, in the examinations, are exempted as passed and allowed into the next class. This section identifies some of the major requirements for an effective learning environment.

3.2.1 Interactivity

In the conventional paradigm of learning students are characterized as passive and merely reacting to authorities. The only interaction between teacher and student during lesson time is authoritarian and mostly unidirectional with the teacher being clearly superior to the student. Students might ask a question or two, but this is not likely because the student will remain passive most of the time during a lesson.

This is not a setting conducive to learning, because a learner “does not passively absorb knowledge from the world around him but must play an active role” (Skinner, 1968). Skinner goes to explain that learners learn by doing, experiencing, and engaging in trial and error. These three components of learning must all be fulfilled for any given instance of learning (Skinner, 1968). It must be pointed out that, “the emphasis is on the active responding of the learner. The learner must be engaged in the behaviour in order to learn and to validate that learning has occurred” (Burton et al, 1996).

> *Interactions cause differential allocation of cognitive resources in accordance with the learner's familiarity with the domain under study. As critical aspects of the domain become familiar, the associated cognitive processes become automated, requiring few or no cognitive resources"* (Hannafin et al, 1996).

This differential allocation encourages the learner to formulate an individual database or schema of understanding, and relate this understanding with the way that they perceive the lesson, which is different for each individual learner. This stimulates understanding and deeper insight into the subject matter as opposed to mere memorization the subject. Of course, there are certain things that a learner should commit to memory, but memory or the ability to memorize alone cannot serve as a basis for effective learning.

Moore (1989), in his model, discusses three types of interaction essential in the delivery of education. Learner-instructor interaction is that component of his model that provides motivation, feedback, and dialogue between the teacher and student. Learner-content interaction is the method by which students obtain intellectual information from the material. Learner-learner interaction is the exchange of information, ideas, and dialogue that occur between students about the course, whether this happens in a structured or non-structured manner. The concept of interaction is fundamental to the effectiveness of distance education programs as well as traditional ones (Moore, 1989). Hillman, Willis and Gunawardena (1994) note that the interaction between the learner and the technology that delivers instruction is a critical component of the model. This is because learners should be able to understand the interface with the delivery medium or else they will waste time learning how to interact with the technology, time that should be spent learning the lesson.

3.2.2 Control

Control is a necessary element of learning that has to be taken into consideration in the proposed technological solution. "The approach is to emphasize the learner's freedom to choose those learning activities that suit his or her own individual preferences and needs", (Williams, 1992). This would be very appropriate for the South African high school system, where learners choose to do their subjects either in higher or lower grades. The learners would be able to choose between the two grading systems in any subject they are occupied with. Learners need to have more independence and control of the educational content for a more effective learning environment. Williams describes learner-controlled instruction as those instructional designs where learners make their own decisions regarding some aspect of the "path", "flow", or "events" of instruction (Williams, 1992).

Leaner control has been found to stimulate achievement and improve attitudes and motivation (Kinzie, 1990). Kohn (1993) suggests that learner control improves self-attribution, achievement, and behaviour. Studies that have been carried out by Altmann and Arambasich (1982) suggest that, "students who perceive their academic success as a result of their own personal accomplishments have an internal locus of control and are more likely to persist in their education". This is a positive attitude that should help the student not only during their high school academic life, but will also come in handy at any time during their lifelong learning. Altmann and Arambasich suggest that, "students with external locus of control feel that their success or lack of it, is due largely to events such as luck or fate outside their control." This suggests that students with external control are likely to be dropouts in education.

The drawback of learner control is the fact that learners may not necessarily always focus and engage on the subject and may go and wander into other territories outside what they are supposed to learn. "Learners have also proved poor judges of their learning needs, often seeking information that is not needed or terminating lessons prematurely" (Hannafin, 1984). The proposed technological solution will absolutely also need to address this critical drawback of disengagement, because there is a risk of students wasting a lot of time, and not having the necessary work done in good time.

Learner control also brings the possibility of allowing the student to do their work at their most appropriate time and pace. This is an important feature suitable to the different abilities and comprehension rates that students have. It also gives a make up chance for students who, for some reason, had to miss the normal attendance time.

3.2.3 Media

As early as in 1933 experiments conducted by Koon have shown that, “media increases initial learning, effects an economy of time in learning, increases permanence of learning, aids in teaching backward children and motivates learning” (Koon, 1934). When Koon made this statement in 1933, he was referring to what was then termed audiovisual instruction (today better known as multimedia instruction). Since then, there have been a lot of advancements in the field of educational technology in providing multi-modal presentation in education. The different stimuli that a learner is possible to be exposed to in a multi-modal presentation are any combination of text, sound, and visual material. Most of the time, in the conventional classroom setting, educational material is presented in text in the form of textbooks. Gropper suggests that visual material should help students acquire, retain, and transfer responses, because visuals have the capacity to cue and reinforce specified responses (Gropper, 1963). Visual materials should invoke the learner’s use of photographic memory, which is a much less volatile memory than factual memory.

A substantial amount of research has been carried out in the relationship between effectiveness of learning and media richness of a lesson. It is widely assumed that multi-modal instruction enhances learning more than information presented from a single source (Clark, 1985). A series of meta-analyses, including that of Kulik, Bangert and Williams (1983) suggested that students in treatments using media systems consistently scored slightly better on tests than did those in traditional classroom contexts. Paivio hypothesized a model which stated that the two types of information, i.e. verbal and imaginary, are encoded by separate subsystems, one specialized for sensory images and the other specialized for verbal language. The two systems are assumed to be structurally and functionally distinct. Audiovisual Information may be encoded once as a picture and again by the verbal description given to the picture, and he called this process dual coding. In contrast, text is encoded only once, via a verbal channel. Information that is processed more than once often adds to the ability to be recalled and retrieved easier than information that has been encoded once. This so-called "dual-coding" of information essentially doubles the probability that it will be recalled (Paivio, 1979). According to Dunston visuals, "are readily recalled and, when associated with important content, tend to enhance recall of that information." (Dunston, 1992).

3.3 Computer Aided Learning

It has not been too long since the invention of the computer, but already there are many things that it is hard to imagine how they could be done without the use of a computer. The computer is a highly versatile tool for numerous tasks, and education delivery is one of them. For the purpose of education, computers provide features that are not readily available with the other types of delivery media.

> *The computer can be patient, user friendly and personalized, non-judgmental and non-emotional, … give undivided attention and immediate, continuous positive reinforcement. For the reluctant reader, computers offer an interactive environment, which is not possible with a book* (Pilla, 1987).

Research has indicated that the nature of computer-based learning creates a more positive attitude in those students who previously experienced difficulty and failure in their learning. The lower the grade or ability of students, the more effective computer-based instruction is (Balajthy, 1989). This is especially appropriate for learners with special needs, who would otherwise be considered incapable of learning in conventional settings.

"The computer can provide illustration, animation, interaction and feedback to assist and enrich learning" (Bogle et al., 1997). Multimedia content in computer-based education also provides for simulations that "are used to teach students about many topics, in part, because the mental and physical dexterity required to use a simulation, engages students in learning" (Anderson, 1983). The engagement factor in the use of computers helps to keep the student focused on the work that has to be done. "Often simulations are used to stimulate students' interest in a topic, and promote active learning, problem solving, and the study of processes" (Hartley, 1988). It is not surprising, therefore, that many believe that use of computers and other information technologies will inherently improve learning (Clark, 1985).

To interact with the intellectual material in the lesson, the student has to learn to interact with the technology of delivery, first. In computer-based education, this means that the student has to learn to use the computer or they will waste valuable lesson time. Learning the computer is a good by-product of learning through computer-based education. Computer literacy is a skill and a demand that a student will face in life whether in higher education or at work for the foreseeable future.

Computers can augment the learner's problem-solving capabilities by managing available data and performing requisite transformations and calculations (Pea, 1992). The transformational capabilities of the computer facilitate problem representation by helping to clarify relationships between symbolic representations and physical events. This will help the students to form more accurate mental representations of physical phenomena. Through direct manipulation and experimentation, learners often discover important underlying processes, principles, and logic that result in problems or alter the problems in important ways (Pea, 1992). An example of this effect is the manipulation and changing of variables within a given simulation program so as to experiment on how the overall result will change. Reiber reported that systematically manipulating the attributes of animation significantly facilitated learning task, that is, when the animated object's attributes are consonant with the learning task (Reiber, 1990).

Computer mediated communication also plays a role in reducing discrimination by providing equality of social interaction among all participants who may be anonymous in terms of gender, race, and physical features.

3.4 Asynchronous communication

Technologies utilized for delivery of education can be classified as one-way transmission, or two-way interactive technologies. Technologies that permit two-way interaction can be classified as either synchronous (real-time communication) or asynchronous (time-delayed) systems. Synchronous communication is mostly used in group teaching where a number of learners gather together to be present at a lesson. An example of synchronous delivery of educational content is during a videoconferencing session where students attend to a lesson as a group rather than individuals. The synchronous delivery mechanism closely resembles the conventional in-class teacher/student relationship where the teacher stands in front of a class and talks to a group of students.

Asynchronous communication is mostly used for individual learning. Asynchronous teaching is where the content presented is not "live" and viewed at the discretion of the user and at the user's pace and time.

> *Group teaching/learning is a teacher-centered form of education, and individual teacher/learning is a student-centered approach to education* (Daniel, 1996).

It can, therefore, be deduced that a system, which is to allow for individual learner control, must be an asynchronous system.

> *Asynchronous communication technologies like electronic mail, bulletin boards and listservs can facilitate discussion between teachers and experts, teachers and learners, and learners amongst one another* (Mostert, 2000).

This promotes the teacher-learner interaction as well as the learner-leaner interaction, which have been described in section 3.2. "It is human nature to find ways to convert synchronous communications into asynchronous forms" (Gates, 1995). In asynchronous communication, "students consciously stand back from their experience and then, having reflected upon it, argue about it" (Laurillard, 1993). In asynchronous systems, "students are also given time to reflect on the problems posed and compose a more considered answer at their own pace, improving critical thinking and communication skills" (Bogle et al., 1997).

3.5 Conclusion

From the discussions argued in the above sections, the basic elements that need to be addressed by the proposed system have been deduced, which are interactivity, control, and richness of media. A summary of the attributes of each necessary element for effective learning is tabulated in table 3.1.

LEARNING ELEMENT	ATTRIBUTES SUMMARY
Interactivity	Interactivity is the ability of the delivery technology to offer collaborative interaction between the teacher and the learner or between the technology and the learner or amongst learners themselves.
Control	Control is the learner's freedom in choosing only the learning material that they need. Control is also concerned with the learner's independence in choosing the time and the pace at which the learning material is grasped.
Media	Media is concerned with each technology's richness of media in presenting information in more than one form such as text, images, video, and sound.

Table 3.1 Summary of the learning elements' attributes

The system also has to be able to facilitate engagement of the student to the lesson content. Even the most engaging system does not guarantee that all the students will do the intended work, so the proposed system has to find a means of monitoring the progress and the amount of work that has been done over a certain period. The system must also provide for self-driven and individual learning.

From the pool of different educational content delivery systems that were discussed in Chapter 2 it can be deduced that a computer-based education delivery system has the required capabilities to furnish the requirements for effective learning. It is clear that the system has to be an interactive computer-based system that is capable of providing interactivity, control, and multimedia content. Computer-based education meets all the requirements and also offers more capabilities that are not readily available in other delivery methods.

There are various types of computer-aided learning technologies that are different in various technical aspects. The next chapter investigates thin client technologies and their suitability for the proposed deployment environment.

Chapter 4

The Thin Client Computer Network Model

4.1 Context

In the previous chapters it has been concluded that, in the ideal situation, the proposed solution would be a computer network that is able to cater for self-driven and self-paced learning by enabling the users to access educational material stored in the central information depository of the system as they wish, i.e. at their own time and pace. The system must be able to provide for learner-instructor, learner-content, and learner-learner interactions, and the system should be able to deliver multimedia content. These are some of the vital elements for an effective learning environment, as discussed in the previous chapter. Also, the network should enable the instructor to monitor the progress of each student, so that the teacher can facilitate help wherever necessary. Computer networks in general, are able to afford all the above-mentioned requirements.

Any investment is based on economic value of the investment, and costs are one way of determining the economic value of an investment. In an Information Technology (IT) investment, it is not sufficient to consider only the cost of acquiring the hardware and software, because the cost values reflected in such an evaluation are superficial and do not take into account other costs that are involved in the longer term. It is for this reason that research companies like the Tolly Group, Gartner Group and various other individual research companies have developed models for calculating the costs incurred in an IT investment in a more comprehensive manner. A lot of companies have investigated the Total Cost of Ownership (TCO) of an IT investment and the thin client/server model has been approbated as a very cost-effective solution because of its lower cost of ownership in the long term and its reduced complexity of operation. It is for this reason that this model has been particularly investigated in this research study. The thin client/server model is a sub-class of a more general model of the client/server model. In this chapter the features of the thin client/server model are investigated and the characteristics that make it different from conventional client/server model are highlighted.

4.2 Client/server model

The client/server paradigm in networked computing has become the general system architecture of choice in scenarios where a significant number of multiple users require access to a single pool of shared data resources and applications.

The server is a centralized computer that is optimised to perform data handling and data processing functions, preparing data for shared use between multiple users. The computer on the user's side is called a client. The server's main purpose is to provide information and services to the client, and the client requests information and services from the server. The client/server architecture is different from the peer-to-peer network architecture, where there is no need for a centralized computer to act as a server. In peer-to-peer network architecture each of the computers in the network acts as both a server and a client. Although it is cheaper, easier to install and maintain, the peer-to-peer network architecture is very limited in terms of the number of computers that can be on the network, thereby limiting its expandability. Data transmission in peer-to-peer networks is slow, and the security is poor since there is no central information depository. The proposed technological system must have a secure central information depository where the educational material will be stored and made accessible to the learner. The peer-to-peer network architecture does not meet these requirements and therefore would not be suitable for the delivery of educational content.

The fundamental characteristic of client/server network computing is that the computer applications and processing are distributed over the network, with part of the applications on the client computer and another part on the server computer. Client/server architecture uses modular programming by dividing large software into smaller modules. These smaller modules can be executed in different memory spaces located in different computers. The calling module is the client, which requests services from the server, and the called module is the server. Although the client/server configuration is more expensive to buy and maintain than its peer-to-peer counterpart, it is more suitable and offers a more reliable service for the purpose of delivering educational content. The client/server architecture can either be a two-tier architecture or a three-tier (multi-tier) architecture. A two-tier architecture is where the client talks directly to the server without any mediating computer in between, whereas there is at least one agent server between the main server and the client in a three-tier architecture.

4.3 Thin Client/server model

A thin client can be broadly defined as a desktop device, connected over a network to a central computer or server operating in multi-user mode (Wyse Technology, 1998). A thin client/server network falls under the client/server architecture, but it is different from the typical client/server network defined in the section 4.2. The major difference between a thin client/server architecture and a conventional client/server architecture is that while the data processing is distributed and shared between the client and the server through cooperative processing in the conventional client/server, processing of data is entirely left to the server in the thin client/server model. All that the client does is to provide the user with a window into the operations of the server, where the processing takes place and the applications reside, hence the name thin client. Thin clients vary in their thinness from the thinnest clients to the hybrid netPC. The netPC is a hybrid between the conventional and the thin client/server models because some processing does take place on the client side of the netPC although it is very limited and under centralized control.

In this project we will only consider the thinnest of the clients, where data storage and all processing take place on the server. For the purpose of intelligibility, thin clients will be contrasted and compared to the conventional client/server-computing environment. This will help to clarify any ambiguities between the two architectures. The conventional client/server user stations are also known as fat clients due to the fact that the client stations have enough processing power and data storage capacity to operate as stand-alone computers when not attached to a network.

There are a number of thin client models from different vendors in the market. For this project the Citrix Systems' thin client/server model will be used as an illustration and a system of choice. The reason for this choice is that the Citrix model has been widely deployed in several applications in industry. The Citrix technology is also incorporated into the Microsoft Windows 2000/NT Terminal Server, which is one of the most widely used server operating systems in the world. A brief history of Citrix Systems is discussed in the next section.

4.4 History of Citrix Systems

The Citrix MultiWin technology was first conceived by Ed Iacobucci in the late 1980s who is the chairman and the chief technical officer of Citrix Systems, Inc (Mathers, 2000). Ed Iacobucci worked for IBM from 1978 to 1989 as an operating systems designer and architecture. He was also the head of the design team for the OS/2 operating system, which was a joint collaboration between Microsoft and IBM. While he was working on the OS/2 project he, "envisioned a way to allow different types of computers on a network to run OS/2 even though they weren't built to do so" (Mathers, 2000). This is how the idea of MultiWin was conceived. When he introduced his idea to Microsoft and IBM, neither were interested, and so he left IBM to form Citrix Systems in 1989.

The technology that Ed had envisaged, called MultiView at the time, worked well. The problem was that it had been developed whilst he was working on the OS/2 operating system and as a result this technology only worked within the realm of that operating system. Unfortunately the future of the OS/2 operating system looked very faint at the time. He then decided to build the Citrix technology based on Windows NT, and Microsoft Corporation saw this as something that would help to expand Windows NT market, which was not doing so well at the time. On May 12, 1997 Citrix and Microsoft signed a joint development and marketing agreement whereby Microsoft licensed MultiWin multi-user technology (previously MultiView) from Citrix and endorsed the Citrix thin client/server presentation services protocol, called Independent Computing Architecture (ICA) (Mathers, 2000). The combination of ICA and the MultiWin multi-user technology is what produces the Citrix WinFrame system's thin client/server technology, which runs and is incorporated within the Microsoft Windows NT/2000 server operating system.

4.5 Features of the thin-client/server environment

Thin client/server networks are flexible and work with both two-tier client/server and three-tier architectures, i.e. each client can have a dedicated direct link to the server without any intervening agent computer or a multi-tier architecture with several agent servers. The thin client/server architecture has some features that are not inherently found in the conventional fat client/server architecture. In the following chapters, the features of thin clients will also be discussed in perspective of how they meet or not meet the requirements for an effective learning environment as discussed in the previous chapter.

4.5.1 Core features of the Winframe system

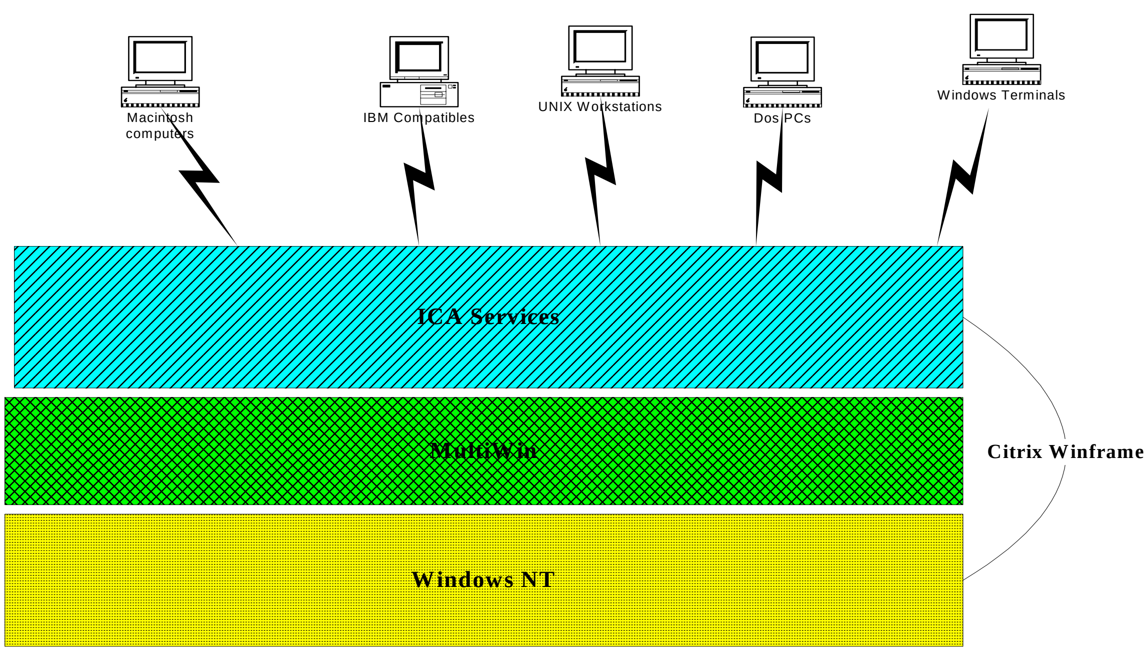

Figure 4.1 The different components of the Winframe architecture

The Citrix Winframe thin client/server technology is made of two core technologies that sit on top of the Windows NT operating system. These technologies are key to the functioning of the Winframe system. Figure 4.1 shows the interrelationship between the different components of the Citrix Winframe architecture.

4.5.2 Citrix MultiWin

The MultiWin is a multi-user layer on the server that simulates local application processing, which makes the client side of the system function as if the applications were executed locally. Citrix created MultiWin as an authorized multi-user extension to Microsoft Windows NT Server. MultiWin technology allows multiple concurrent users to log on and run applications in separate and protected Windows sessions on the server.

> *Virtually any client, from the latest Pentium PCs, Windows Terminals and network computers to legacy DOS PCs, UNIX workstations, Macintosh computers and OS/2 desktops can access the same applications, without special emulation software, changes in system configuration or application rewrites.* (Kanter, 1998)

This MultiWin technology’s client independence enables a variety of devices to access applications in the server. The client only provides a window-view of what is happening on the server and the application processing takes place on the server and not on the client.

4.5.3 Independent Computing Architecture (ICA)

The ICA protocol is general-purpose presentation services protocol. ICA separates the application logic from the user interface at the server and transports it to the client.

> *Separation of the application execution from the display logic reduces the amount of data that needs to be communicated across the network, allowing efficient use of available bandwidth* (Kanter, 1998).

As a result of this separation, only the screen updates, keystrokes, and mouse clicks traverse the network between the client and the server. The bandwidth needed to do this is minimal, which enables the Winframe thin client/server to be used in any network or communication protocol even at very low bandwidth.

> *ICA is designed to run over standard network protocols like TCP/IP, NetBEUI, IPX/SPX and Point-to-Point protocol using standard communications protocols like ISDN, frame relay, ATM and asynchronous connections* (Kanter, 1998).

The ICA client is thin client software that resides on the client station. It sends the mouse clicks and movements, keystrokes to the server and accepts screen updates to be displayed on the client's screen. Figure 4.2 illustrates the functioning of the ICA protocol.

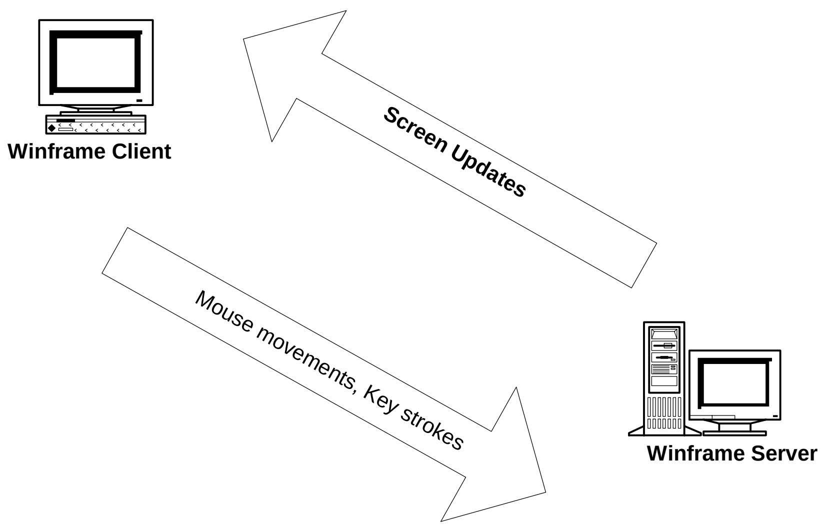

Fig 4.2 The ICA Protocol

> *Using a protocol such as ICA with a local area network (LAN) or a wide area network (WAN) connection, the user experience with many software applications is the same as for applications running on local computer with a full complement of application and operating system software* (Kanter, 1998).

This means that the user-experience of the thin client and performance of the technology is similar to that of a fat client/server experience for most applications.

4.6 Other features

What follows are other features of the thin client/server architecture regardless of the vendor or the manufacturer:

4.6.1 Centralized System Management

In the thin client/server environment all the processing and applications reside on the server. The way that this centralization of network resources impacts the management and utilization of the network is as follows:

I. Software administration

All software applications that users need reside on the server, therefore installation only happens on the server. This is contrary to the fat client/server model whereby software needs to be installed on all the clients on the network. For a large network this can be a matter of days whereas in the thin client/server model this is only done once and finished in a matter of minutes. Any changes that need to be made, like upgrades or software patches to the software, are made only on the server side, and these changes immediately reflect and take effect on all the clients on the network. In the case of fat clients this would have to be done on all the stations on the network resulting in a lot of time spent on upgrading and fixing the software.

II. Hardware administration

The PCs on the client side of a fat client/server network need to be constantly upgraded due to the rapid changes that are made in both computer software and hardware. Sometimes upgrading a PC costs effectively more than buying a new one in which case the old PC has to be thrown away because of obsolescence. This expensive experience does not happen in the thin client/server model. All hardware upgrades like the upgrading of the CPU or addition of more RAM only takes place on the server. The amount of savings in time compared with the fat client/server model is enormous, because the task of hardware upgrades is very labour intensive and time consuming.

III. Data storage

When there is a software upgrade there is automatically a need for an increase in disk space, because the more powerful the software the more disk space is needed on the hard drive. In the fat client/server model, this means that whenever there is new software to be installed or upgraded, there will be upgrades in disk space on each and every client on the network except if provision was made for big enough hard disk drive in each fat client machine. If there is an application upgrade of an application that requires 30MB of disk space then the software will have to be installed on all the clients on the network occupying a total of N*30MB, where N is the number of stations on the network.

The thin client/server architecture is not overwhelmed with this tedious and expensive operation, because changes in disk space only take place on the server where all data storage resides. Increase of RAM, increase of disk space and all other networking hardware changes take place on the server alone.

IV. Session Recovery

Winframe, by default, preserves a user's session if the physical connection between the client and the server is broken (Kanter, 1998). This characteristic provides the client with the ability to recover immediately when there has been a network downtime without losing any of the user's work. Users also have the ability to seamlessly continue with their work on another station and can immediately recover their work from there.

V. Remote Control

Shadowing is a feature that allows for one user to view the activities of another user. The activities can be whatever is shown on the other user's screen, mouse clicks, and keystrokes that are entered by a remote user on another session. This gives the administrator and everyone who has been assigned the necessary rights to view and control the remote users activities as if they were in front of the remote user's station.

4.6.2 Security

The security of the Citrix Winframe architecture is based on the underlying Windows NT server operating system.

> *The Windows NT server provides security through individual and group accounts, user profiles, and the differing levels of security required for the U.S. Department of Defense's C2 security specification* (Kanter, 1998).

All data is centrally stored on the server or on other file servers in the case of a multi-tier architecture. This single point of storage makes it easy for the administrator to make back-ups of data and all sensitive material. This improves security, because only the authorized people are granted the right of access to certain data. Virus checks are easier to render because there is only one single point where this takes place. Users usually are unaware or negligent of the importance of running virus checks and the results of an infection in one station on a network can traverse the entire network.

Stiffy disks are a source of viruses, which are brought into the network by users either deliberately or by mistake. Citrix thin client devices do not have stiffy disk drives, and therefore it is almost impossible for the users to infect the network with viruses from stiffy disks. Sensitive organizational information can also not be saved onto the disks and taken out of the organization.

4.6.3 Use of existing technology

As it has been mentioned before, the thin client/server model operates independently of the client architecture. This enables the system to be able to use legacy systems that may already exist in the organization, instead of throwing them away and migrating completely to an organization-wide compatible system. This has cost implications on an organization's budget.

4.7 Conclusion

From the discussions above it is clear that the thin client/server architecture has some advantages over the conventional fat client/server model. The appropriateness of and how these advantages can benefit the delivery of education in a cost-effective manner in the aforementioned deployment area is the discussed in the next chapter. It must be understood that the thin client/server architecture is not a replacement for fat client/server architecture, because it has its weaknesses whereby the fat client/server option surpasses the thin client/server model.

Thin client/server architecture is not suitable for delivering multimedia content. The ICA protocol that is used in transporting data between the server and the citrix thin clients is a low bandwidth presentation services protocol that can only handle a limited amount of traffic in the thin/client server network. Multimedia applications are very bandwidth intensive and they cannot be managed by the ICA protocol. This disadvantages the learner, because multimedia is one of the desirable elements in the delivery of effective education, as addressed in section 3.2.3.

Another drawback for the thin clients is that the initial investment in acquiring the technology is more than that of the fat clients. This is a weakness that would adversely affect the envisaged deployment area due to the deficiency of funds in the region.

As it has been discussed in the previous chapter, the cost of the proposed system is very important, due to the lack of funds in the area concerned. The cost-effectiveness of the thin client/server solution will be determined in the next chapter.

Chapter 5

Cost Analysis

5.1 Context

The significance of costs have been mentioned in the previous chapters because of the deficiency of funds in the given envisaged deployment region. In this chapter, models for calculating the costs incurred in the deployment of a computer network infrastructure are discussed. This chapter uses different cost models to uncover the costs that are involved in acquiring and owning the proposed IT infrastructure for the delivery of educational content. The costs of the thin client model are constantly compared to the fat client model in order to bring out the differences in the costs of the two architectures.

To illustrate the differences in costs of the different computer network architectures, a comparative example involving monetary figures for the costs is provided through a research study conducted by a reputable research institute. The example used is the Tolly Research Group's Total Cost of Application ownership (TCA) calculator, which is a contemporary tool for calculating and comparing the total cost of application ownership. The default exemplary illustration used in the TCA calculator of 2500 users is used as an illustrative instance. Also the costs incurred per user over a period of time are reflected. The amounts reflected in this study are in US dollars, because the study was carried out in the United States of America.

As a proof of concept, a real-life situation of the deployment of thin client architecture by an industrial organization, Telkom is used as a case study to illustrate the cost implications of deploying this technology. Telkom is a South African telecommunications company, which is very dependent on its IT infrastructure for maintaining a competitive edge. One of Telkom's aims for the deployment of the IT infrastructure is in the training of their staff through their Center For Learning (CFL).

This is one of the reasons why Telkom has been chosen as a case study in this evaluation. Another reason behind the choice of Telkom as a case study is that they have the largest investment in the deployment of the thin client architecture in the country. The amounts reflected are in South African Rand, because the company is a South African company. In this study we are interested in the relative costs of thin client and fat client solutions, so the switch between currencies should not cause confusion.

5.2 Models for calculating costs

There are several models for estimating the total cost of a network infrastructure. Two of the most widely used models are the Total Cost of Ownership (TCO), and the Total Cost of Application Ownership (TCA). These models have been developed and used by well-known independent research institutes with reliable research reputations who are assumed to be unbiased in their evaluations. The TCO model used in this study, which was developed by the Gartner group, is a model that helps investors to understand and manage the direct and indirect costs that are incurred in owning and using an IT infrastructure throughout the technology's life cycle (Gartner Group, 1997). As illustrated in figure 5.1, this model is a continuous cycle of cost analysis revolving around the users and the tasks that they have to accomplish. The analysis cycles through the technology's life cycle from its acquisition to its deployment, and continues to its operations within an organization up to the end of its lifetime when there has to be new replacements.

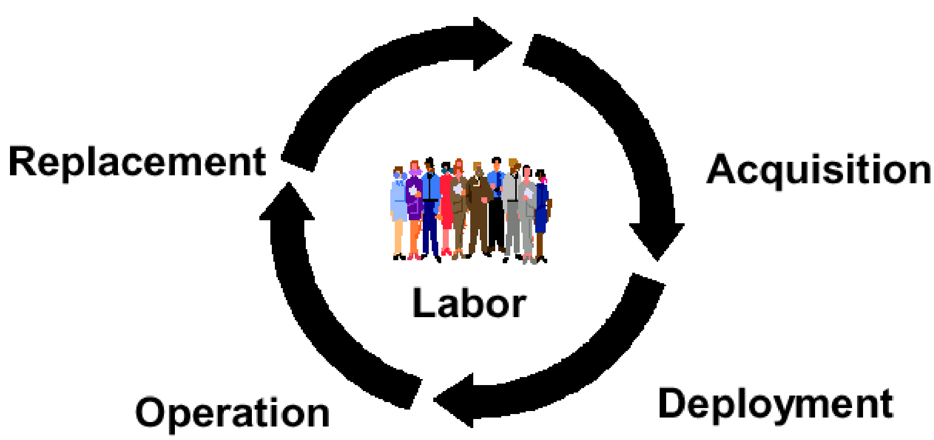

Figure 5.1 Life cycle of an IT infrastructure (Gartner Group, 1997)

According to the Gartner Group, the TCO is to be evaluated throughout those stages so as to give a more precise estimate of the total cost of ownership.

In the Gartner TCO model costs are divided into two categories. The direct costs are the costs that have been budgeted for, and indirect costs are those that have not been budgeted for. The TCO model acknowledges the fact that cost of hardware and software are coupled with other costs such as network administration costs, repairs, and downtime costs. This model has a comprehensive analysis on costs, because it encompasses the costs of ownership over the short and the long term of the product life cycle.

The TCA model, which was developed by the Tolly Group, is a more detailed model of estimating the total cost of owning and using a computer network infrastructure.

> *The TCA Calculator provides a more accurate presentation of IT costs because it considers the growing number of options and complexities IT professionals face when choosing how to deploy an application to users around the world.* (Tolly Group, 1999)

In essence the TCA model builds upon the TCO model and provides a more accurate estimate by encompassing factors such as “how applications are deployed, the locations of users, the variety of connectivity options and the varied types of client devices.”(Tolly Group, 1999)

The TCO can be viewed as a product-centric approach in cost analysis while the TCA is an application-centric approach to cost analysis. For the purpose of this study both the TCO and the TCA models will be used for evaluating the cost implications of a thin client IT infrastructure for the delivery of educational content. The TCA model will be used to a larger extent than the TCO model. The reason for this is that all of the components and factors that make up the TCO model are addressed within the TCA model. Although the TCA calculator is more focused on the applications, there are some useful product-centric cost elements within the TCA model that will be used in this analysis.

5.3 Components for Calculating the Cost of Ownership

There are a number of TCO models, developed by various organizations, which produce different cost figures and therefore there are no authoritative figures in absolute terms. The TCO is a combination of direct and indirect costs mentioned in section 5.2**.** The direct costs or hard costs are easy to quantify by "determining the hardware and software required and then total their cost" (Mathers, 2000). The indirect or soft costs are "much more difficult to measure before hand and are very often based on historical data" (Mathers, 2000). This difficulty in quantifying the soft costs is the reason why different TCO models that have been developed by different organizations, produce varying figures. Although these different companies have varying figures, they all agree that the soft costs far outweigh the hard costs in the long run.

For the purpose of this evaluation, the TCO will be divided into two categories, which are the hard costs and the soft costs. The cost implications on using thin clients and fat clients are discussed under each category. The use of thin client architecture is compared to that of the conventional fat client architecture so as to illuminate the cost implications in both architectures.

> *The idea of TCO is simple: Maximize the company's return on investment (ROI) in technology while minimizing the cost involved in doing so* (Mathers, 2000)

What the conception of TCO "really boils down to is getting the most out of your technology investment with the least amount of unnecessary effort" (Kanter, 1998).

5.4 Hard Costs

The hard costs are the budgeted costs of acquiring the software and the hardware, and they are fairly straightforward and easily quantifiable.

5.4.1 Software costs

Software licensing issues in the fat and thin client architectures are different in the way that they are computed. In both architectures there is a necessity for the Network Operating System (NOS), which will reside on the server.

In fat client networks an individual client-based license is required for each client station on the network, whether it is in use or not. For example, if a fat client network has 50 clients on it, there is a requirement for 50 licenses, one for each client, in order for the individual clients to log onto the network, even if only 25 clients are using the network at a time. This type licensing is called a per-seat license (Kanter, 1998).

In a thin client network a server-based user license is used instead. This type of license is called a per-server license, and it allows a specified maximum number of clients to log onto the network server at a time (Kanter, 1998). For example, if 25 Citrix licenses are installed on a Winframe server, a maximum of 25 clients can be logged onto the network at a time even if there are more clients on the network. The 25 clients don't have to be the same clients every time. Effectively, you can have 50 clients on this thin client network and any 25 out of the 50 clients would be able to log on concurrently at any given time (Mathers, 2000). For the clients to be able to connect to the Winframe server, they must all have the ICA client installed or embedded in the client system. This adds more costs in software acquisition for the thin client architecture. The per-server licensing option allows for a more cost-effective use of licensing funds. For example, if one client is down, the other client stations on the network will still be left with the same maximum number of licenses available for use at anytime. In a fat client network, when a client goes down, it goes with its license funds intact.

5.4.2 Hardware costs

The hardware costs for both the fat and thin clients are calculated using the same approach. The total costs per architecture are the costs of the client stations plus the cost of the server(s).

In a fat client network, the server's specifications are not as demanding as in the thin client scenario. Since the data processing is distributed over the entire network in fat clients, the server does not need to have very powerful processing abilities, because client stations have their own processing abilities. Most of the user's data storage in fat client is done at the client side and therefore the server is not required to have large amounts of storage disk space compared to its thin client counterpart.

In thin clients the server is the fat part of the architecture, meaning that it has to be loaded with high specifications so as to serve the thin clients adequately. The thin client server is responsible for data processing and all data storage. In response to this demand the thin client server is required to have a lot of disk space for data storage, a large amount of Random Access Memory (RAM), and high processing power. Depending on the number of clients on the network and type of applications that the users utilize, there may be a need for a server farm with more than one server, so as to cope with the client demands.

The initial total hard costs of hardware and software acquisition are more favourable for the conventional fat client configuration than they are for thin client architecture. The research study figures in the TCA appendices concur with this perception, where a comparison is made between the total hard costs of acquisition of the conventional PC based fat client network and a thin client network. The costs of training the users for both architectures are assumed to be the same. The initial hard costs do not reflect the entire TCO analysis, because the TCO is evaluated over the entire life cycle of the product, as shown in figure 5.1. The soft costs are also part of the analysis.

5.5 Soft costs

Soft costs are usually associated with end-user support costs.

> *In most situations the majority of the soft costs are incurred at the end-user's desktop* (Mathers, 2000).

The soft costs are TCO and TCA cost elements that are much more difficult to quantify than the hard costs. According to the Gartner Group, the unbudgeted (indirect) costs can be classified as end-user soft costs and downtime costs (Gartner Group, 1997). The end-user soft costs fall into three general categories: hardware maintenance, application support, and end-user support (Mathers, 2000).

5.5.1 Hardware maintenance costs

The measurement of a device's reliability is the mean time between failures (MTBF). The MTBF is determined by robustness and vulnerability of the complete unit as well as its parts (Wyse Technology, 1998). The physical configuration differences between the end-user clients of the two architectures in comparison i.e. the fat and the thin end-user clients have an influence on the cost of maintenance of each client.

I. <u>Fat clients</u>

A fat client desktop personal computer (PC) is a complex piece of hardware with a lot of electronic components inside it. The more complex the desktop device, the more likely that things can go wrong and therefore the higher the failure rate (Wyse Technology, 1998). The MTBF of PCs (fat clients) is quoted to be 20 000 to 40 000 hours (Wyse Technology, 1998). The following are factors that affect the robustness and vulnerability of a fat client PC configuration:

- The PC has moving mechanical parts inside it e.g. fans, hard disk drives, floppy disk drives and so on, which increase the likelihood of failure.
- The fat PC also has removable parts, which increases the rate of failure.

> *Any device containing parts that can be removed or accessed by the casual user has an increased chance of failure* (Wyse Technology, 1998).

- A lot of heat gets generated while a PC is in operation due to the processor chip that runs the PC, and the mechanical motors in the hard drives, floppy disk drives and so on. This results in a need for fans to cool the system down, and maintain the components within an operating temperature. Unfortunately fans have a tendency to draw corrosive dust and contaminants to the system that can degrade the chip's performance and cause random errors (Wyse Technology, 1998).

These vulnerabilities have an influence in the longevity of the PC, which is expected to fail at least once in its 3-year (26,000 hours) working life (Wyse Technology, 1998).

II. Thin clients

A thin client desktop device is far less complex than its fat counterpart. It is a simple device that has its parts concealed in a tamper-proof casing. Its simplicity in physical design makes it less likely to fail in comparison with the PC client. The MTBF of a thin client desktop is up to 170,000 hours (Wyse Technology, 1998). The following are some factors that affect the robustness of the thin client desktop:

- The thin client has no moving parts inside the device, no hard disk, and no floppy disk. This significantly decreases the rate of failure when compared to the fat client device. The tamper-resistant casing makes it inaccessible to the casual user.

- The heat that is generated by the device when in operation is negligible, such that there is no need for fans inside the device. The absence of fans makes it less vulnerable to contaminants and corrosive dust. The fact that it is enclosed in a tamper-resistant solid casing also eliminates contaminants of any form to penetrate the device.

These factors contribute in making the thin client desktop device to last much longer than a fat client, and requiring much less maintenance from technical support. Since these factors are directly linked to the TCO and TCA of both infrastructures, they can be viewed as cost elements that will influence the TCO and TCA of the different architectures.

> *Personal computers are likely to fail up to five times more often than thin client windows based terminals* (Wyse Technology, 1998).

5.5.2 Application support

The cost of supporting the applications that the users utilize for accomplishing their tasks is vital to consider, because when there is a fault with the application there is no work produced whether in an educational or industrial environment. The different architectures in comparison have different cost implications in the way that these costs are managed.

> *It has been estimated that every commercially available software package in broad circulation today undergoes two to three administrative upgrades per year (bug fixing) and a major release upgrade at least once a year* (Wyse Technology, 1998).

I. Fat clients

- The software and applications that are used by the user are stored locally on the fat client's hard disk. This means that when there is an application to be installed for a group of users, it has to be installed on all the clients on the network. The operating system as well has to be installed individually on all the machines. This has high cost implications in terms of time and resources spent.
- When the software and applications needs to be upgraded or patches installed, this has to be done on all of the machines individually.
- Applications that reside on the hard disk run the risk of being fiddled with by the user causing a need for reinstallation through image ghosting.

II. Thin clients

- The software and the applications that users utilize all reside on the server. All software and application installations are managed centrally and installed on the server.
- All upgrades and bug fixes are also managed at the server and are entirely transparent to the user.
- The casual user cannot tamper with the applications, because they all reside on the server and their configuration is inaccessible to the user.

These factors indicate that the time and resources spent on installing and maintaining the health of software and applications on the different architectures is more favourable for the thin client architecture. The larger the number of clients on the network, the more that these differences are accentuated and they directly influence the TCA of each architecture. Lower resources and time spent on maintaining the applications entails lower TCA. These costs are manifested by the high rate at which upgrades and bug fixes have to be done on applications.

5.5.3 End-user support

The end-user support costs involve providing assistance in using an application, configuring printers, scanning and removing viruses, and fixing desktop configurations that have been changed by the user (Mathers, 2000). These costs are influenced by the following factors:

I. Fat clients

- The configuration of a fat client desktop is such that the system configuration file of the device is stored locally on the client and accessible to the casual user. This brings the possibility of user-caused problems, which are common with users trying to change the system configuration of the client machine.
- The user of a fat client has the ability to install personal software on the machine through stiffy disks. The user's personal software may be incompatible with the system or the stiffy disks may be infected with viruses. This affects the health of the machine and viruses may affect other users on the network. The repairs cost time and money, which will influence the TCA.

II. Thin clients

- The configuration of the thin client device is not accessible to the casual user because it resides on the server and therefore cannot be altered without the network administrator's concern. The possibility of user-caused problems is minimized in the thin client set-up.

- A pure thin client device has no stiffy disk drive, and therefore there is no possibility of introducing foreign material to the system or the network through stiffy disks.

The centralized management of the system resources in thin client network makes it to be less susceptible to end-user generated faults destined for either the network or the client itself or both, whether these faults are unknowingly or maliciously generated. The downtime that is caused by these faults has a direct impact on user productivity and therefore the TCO and TCA of the architectures.

5.5.4 Downtime support

> *Downtime is the lost productivity due to planned or unplanned network and system unavailability* (Gartner Group, 1997).

The downtime of the client devices is directly linked to the productivity of users, and to the learning activities in the case of education delivery. It is very important to consider the time that it takes the system or user to recover from a disaster. The following are factors that influence recovery time on the two different architectures in comparison:

I. <u>Fat clients</u>

- The complexity of the PC desktop device makes it a complex task to diagnose where the fault is during downtime. There are a number of possibilities to consider, e.g. is the fault with hardware or software? If with hardware, is it the hard disk, the floppy disk, the processor, or any of the connected peripherals? If software, is it the operating system or one of the applications? and so on. The various questions to be answered result in a longer time to diagnose the fault, which equates to more costs.

- Since the user's data resides in the fat client's hard disk, the user cannot do their work when the PC is taken out for repairs. This results in a loss in productivity.

II. Thin client

- The time to diagnose a fault in thin clients is much less than in fat clients, because of the thin client's simple configuration. In diagnosing a fault there are only two questions to consider: Does the desktop device run or not? If it runs, does it connect to the server or not? There is no operating system or application to diagnose in the device, because none of those resides on the client itself.
- In the case of the device having to be taken for repairs, another device can be exchanged for the faulty device and the user can access their data and applications, which all reside on the server, from the new device. Alternatively, the user can log onto another machine and access their applications and data from there. These options provide for immediate recovery from disaster.

From the above-mentioned factors, it is obvious that the recovery time for the user to be up and running is much less in thin clients than in fat clients. While it could be a matter of days for the fat client user to be able to access their data, it is a matter of minutes for the thin client user to be productive again. These differences in time to recover have huge implications on the TCO and TCA analyses.

5.5.5 Security

Security of the applications and data has an effect on the TCO. If the security and well being of applications and data is compromised, the productivity of the users is directly affected. The factors that influence security of each architecture are discussed below:

I. Fat clients

- Since the applications run locally on the client's desktop, the security of the application is vulnerable, because the users can alter the configuration of the applications and system files.
- The user has the ability to make copies of sensitive organizational data from the client's hard disk onto a portable medium like a stiffy disk.
- Unlicensed copies of the application can be made by the user from the from the client's hard disk to a portable medium.
- Viruses can be introduced to the desktop system through portable media and these viruses can traverse the entire network, affecting a lot of other users.

II. Thin clients

- The centralized management of network resources in thin clients eliminates the ability for users to copy or modify application files.

> *Control of unauthorized or unlicensed use of software is simplified, and piracy is eliminated* (Wyse Technology, 1998).

- User data and applications are more secure in the thin client architecture.

> *Lacking local data storage or retrieval, and the ability to introduce foreign material, they* (thin clients) *offer the IT manager a dramatically better guarantee of system security than a personal computer* (Wyse Technology, 1998).

It is clear from the above-mentioned factors that the security of data and applications in the two architectures is more auspicious in the thin client architecture.

5.6 The Tolly Group TCA model

> *The Tolly Group provides strategic consulting, independent testing, and industry analysis. It offers a full range of services designed to furnish both vendor and end-user communities with authoritative, unbiased information. The Tolly Group is recognized worldwide for its expertise in assessing leading-edge technologies* (Tolly Group, 1999).

The reports generated from the TCA Calculator, developed by the Tolly Group, are used to show the cost analysis for different computer architectures. The figures in the reports are the default exemplary values in the TCA calculator based on an installation of 2500 clients. The size of the client base is not significant to this study, because the figure exists only for the purpose of comparing the same number of clients for both the fat client architecture and the thin client architecture. The reason for this is that most of the cost elements that are involved in calculating the TCA are scalable according to the size of the installation, and therefore the relative cost savings remain the same regardless of the size of the client base. The main agenda in the TCA calculator is to show the difference in total costs incurred in acquiring and maintaining an IT infrastructure for the same number of users over the same period of time.

In the course of developing the TCA calculator, the Tolly Group extensively researched data and conducted on-site interviews with corporate customers. The result was a detailed assessment of costs for developing, acquiring, delivering and maintaining more than 60 applications across multiple industry segments and computing environments (Tolly Group, 1999).

The reports (detailed in the appendices) compare the costs according to deployment method and computing environment for:

- Traditional desktop computing model in which all applications are stored and executed on the desktop
- Customer-defined model in which applications are deployed and costs calculated according to the parameters specified by the user. This model is not significant to this study, because only the thin clients and the fat clients are compared. It has only been made available for the purpose of comparison.
- Citrix ICA model in which all applications reside and execute on the Citrix server, enabling any client device to access the application over any type of connection (Tolly Group, 1999).

The default illustrational reports in the TCA analysis provided by the Tolly Group are conducted for a user base of 2,500 clients in an industrial organization setting, and the total calculations are based on this number of users. All the costs, including the number of hours of support time, are represented in US dollars. The TCA analysis is evaluated over a period of four years.

Appendix A-1 shows the TCA totals for the entire 2,500-client base, which constitutes of all the cost elements as pertinent to an industrial organization. Appendix B-1 is the TCA application deployment model per client instead of the entire client base as shown in appendix A-1.

Appendices A-2 and B-2 are amended versions of the appendices A-1 and B-1, respectively. These appendices have been modified such that they may be applied to educational delivery, and the relative totals have been generated. The cost elements that do not relate to this study of educational content delivery, and costs that are constant in all the architectures are excluded in the amended versions. The rationale behind each cost element, and whether it is relevant to the delivery of education or not, is itemized and discussed in section 5.6.1.

The column for the customer-defined model is not relevant to this study because only the conventional fat client and the Citrix thin client architectures are compared in this study, and therefore this model has been omitted in the amended versions. The main reason for these analyses is to compare the different architectures in terms of the costs incurred over a period of time. Any cost elements that bear the same costs for both architectures do not influence the difference in cost savings, and therefore are not valuable for this analysis. This analysis constantly compares the two architectures by measuring the differences in costs incurred.

5.6.1 Rationalization of the application cost elements

- Initial Costs identify one-time costs that will be incurred in the first year, including all costs associated with application development; client and server software acquisition, application integration, installation and training; and hardware procurement.
- Recurring Costs identify the annual costs that will be incurred in the first year and subsequent three years. These include application maintenance, server operations and technical support costs; user-productivity costs of downtime and building infrastructure costs.
- Application Development details the parameters for developing or customizing an application. The value of these parameters is the same for the compared architectures and therefore will be omitted in the revised appendices A-2 and B-2. Also, this cost has been omitted because the development of the applications to be used in the delivery of education is not a concern for this analysis. The architecture that is being investigated is independent of the applications that will be running on it.
- Client Software Acquisition identifies client software licensing costs on a per client basis.
- Server Software Acquisition identifies server software licensing costs.

- The application integration details the estimated hours of testing that are necessary to integrate the target application into the computing environment.
- Application installation is the rollout cost and identifies the total time and expenses required to install a client application.
- The application training costs are the costs of training the users to use the application. As mentioned earlier in the chapter, these costs are the same for both architectures and therefore have been omitted in the revised appendices.
- Hardware procurement specifies hardware acquisition parameters required to support the target application.
- WAN Network Hardware Infrastructure and usage specify the current WAN usage capacity and performance levels, and the average cost per unit a company spends on a WAN backbone router and a WAN access router. These costs are not relevant to this study, because this evaluation study is only concerned with the LAN infrastructure and therefore these costs have been omitted in the revised versions of the appendices.
- The LAN infrastructure costs are constant and assumed to be the same for the different architectures. These costs are omitted in the revised versions.
- Application maintenance specifies parameters associated with maintaining and upgrading the target application.
- Server operations identifies parameters relating to server operations. These include the average number of hours employees spend backing up and restoring data, monitoring data and operating the network. It also defines costs for training these individuals on an annual basis.
- The technical support costs identifies the annual costs of support contracts and one-time cost of the diagnosis, monitoring and management.
- Loss of productivity identifies the costs associated with a system, or partial system loss when the end users or clients cannot perform their job functions.

- The building infrastructure details the parameters related to the physical infrastructure and real estate of the computing environment. These costs are constant and they are not relevant to this study, and therefore have been excluded in the amended versions (Tolly Group, 1999).

5.6.2 Analysis of results

The following analyses are based on the 2,500-client base that is used in the amended TCA calculator of Appendix A-2 and B-2. The TCA model is built for the USA market and hard-coded in dollars.

I. Initial costs

The difference in the initial cost totals reflected in Appendix A-2 is $4,354,327 - $3,353,581 = **$1 000 746** (excluding the costs that are the same for both architectures).

The fat client architecture has total savings of over a million dollars in the initial setup costs for the 2 500 users.

Similarly, by looking at the TCA application deployment model per client in appendix B-2, it can be deduced that the fat client model has cost savings of **$400** per client in the initial costs. From this data it can deduced that the initial expenditure for the fat client architecture is **30%** cheaper than the initial expenses for thin client architecture.

II. Recurring costs

The difference in the recurring total costs over four years as shown in Appendix A-2 is:

$18,219,643 - $7,332,084 = **$10 887 559**

The thin client architecture has a total savings of over ten million dollars in the recurring costs over a period of four years for 2 500 users.

Similarly, by looking at the TCA application deployment model per client in appendix B-2, the thin client model has cost savings of **$4 295** per client over the four-year term. It can be concluded that the thin client architecture has a total savings of **148%** in recurring costs over a 4-year period.

The difference in the total costs incurred for the two architectures clearly indicates that the thin client has a far lower total cost of ownership in the long term. The fat client may cost less initially by 30%, but it is a far more expensive architecture over a four-year period costing nearly 2.5 times the cost of thin clients.

5.7 Telkom case study

Telkom SA Ltd is a leading telecommunications providing company in the Republic of South Africa and one of the largest employers in the country with more than 50 000 employees. To maintain their competitive edge they have deployed an IT infrastructure that spans the entire country and beyond.

Telkom decided to deploy thin client windows based terminals (WBT) with a pilot project commencing on 19 April 1999. After the successful pilot project the next phase of *PC Replacement business case*, which showed the financial benefits of deploying terminal server architecture as opposed to replacing old PCs with new PCs, was approved by their Funding Council on 5 July 1999. This project entails replacing the existing IT infrastructure, which is made up of PC desktop devices, with WBTs connected to a Windows Terminal Server, instead of replacing the outdated PCs. At Telkom, the PCs normally get replaced after 3 years.

The biggest drive behind this strategy is saving on costs of owning and maintaining the IT equipment. Telkom’s strategy in deploying the thin clients is that of a piecemeal approach of introducing the thin clients gradually instead of full-blown deployment of the technology. This is very attuned with the thin client technology, because of its ability to accommodate desktop devices of any operating system and any architecture as discussed in the previous chapter.

The rationale behind the use of Telkom as a case study is to show the manner in which cost savings are realized as more thin clients are deployed. In a hybrid network containing both fat and thin clients, it can be inferred from Telkom’s deployment strategy that the cost saving are directly proportional to the number of user stations involved, i.e. the more thin clients are deployed, the more that savings in costs will be realized. Telkom’s case study is also relevant to this study, because one of the applications in which the thin client technology is deployed at Telkom is educational content delivery at the Centre For Learning (CFL). Most of the staff at Telkom is trained through the CFL. The table in Appendix C illustrates the difference in costs between the two environments (fat PC and thin WBT), and shows the savings that can be achieved with different WBT/PC mixes in Telkom by comparing various scenarios. A graphical presentation of this table is shown in Appendix D.

The following are assumptions that were used in the Telkom case study in calculating the cost of deployment and ownership:

Total number of desktop devices:	30 000
Cost of Mainstream Desktop PC:	R8 100
PC Replacement cycle	3 years
WBT device & service:	R5 200
WBT device replacement cycle:	9 years
WBT terminal server replacement cycle:	4 years

(Source: Telkom, 1999)

The above figures are based on market costs and manufacturer claims. From the costs in Appendix C and the graph in Appendix D, it can be deduced that the more thin clients are deployed the more cost savings will be realized. This assumes that the same total number of clients (30 000) will be maintained. From the amount of R81 million in the 100% PCs-only strategy to the amount of R48 165 600 in the 20% PC: 80%WBT strategy, the savings are **R32 834 400**.

5.8 Conclusion

Through the Tolly Group research example and the Telkom case study it is clear that the total costs incurred in deploying and owning the thin client architecture are far less than in deploying and owning the fat client architecture. The two scenarios in this chapter, whereby thin clients have been deployed, are both in an industrial setting with a lot of users. The prices that are quoted are for companies who are dependent on the well being of their IT investment, thereby having to purchase and use high quality and expensive equipment. This yields a high price for both acquisition and maintenance of the IT investment. The actual prices quoted would not be realistic in a rural school environment, because of the lack of funds. But the relative costs of deploying and owning thin clients and fat clients are nonetheless important to note.

The prices that are quoted and, as stated before, the number of users in the two scenarios are not significant, because the significance of the two scenarios is to show the enormous difference in costs between the two architectures in comparison. The huge numbers of users and the high equipment prices are used to demonstrate the difference in the TCO, because the larger the investment, the more that cost savings are realized. This is also evident in the Telkom case study, where the more the thin client architecture is deployed, the more that cost savings are realized, provided that the total number of users is kept constant. It can be assumed that the percentage cost savings between the two architectures will remain relatively constant even for a rural school with a smaller number of users and using less expensive equipment. The relative cost savings will be similar whether the technology is deployed in an industrial or educational setting, even for a smaller number of users. This is due to the fact that the cost elements that are used in calculating the TCO, in the amended appendices, all scale according to the magnitude of the deployment. The amended appendices contain the cost elements that may be applied to the education delivery environment. Most of the cost elements that have been used in the amended appendices for calculating the TCA are scalable according to the size and function of the environment of deployment. This implies that relative savings will be realized even in a smaller installation with fewer users and less expensive equipment.

Whilst costs are an important aspect to consider, it is important to maintain a high level of user functionality in an IT infrastructure. As figure 5.1 shows, the life cycle of an IT infrastructure revolves around the people who use it. The infrastructure must be able to deliver the required functionality in order for the people who use the infrastructure to be able to accomplish their tasks. The functionality of the network and its ability to deliver the workplace requirements are discussed in the next chapter. How these requirements at work are related to the educational requirements is also discussed in the next chapter.

Chapter 6

Applications Analysis

6.1 Context

The functionality and quality of service offered by the proposed technology is an important element in the proposal, because if it cannot meet the requirements of the users then it is clearly not worth considering. As has been discussed in Chapter 3, the requirements for an effective learning experience have to be met by the proposed technology. The thin client technology's capabilities in meeting those requirements are addressed in this chapter. The behaviour of the thin clients under various test conditions will be investigated. The most desirable requirements are discussed and those that cannot be met by the technology are also addressed. Things that should be avoided when using the technology are also dealt with in this chapter.

6.2 Telkom Test Case

As discussed in the case study in the previous chapter, Telkom has deployed the thin client solution in order to reduce the total cost of ownership. Before deploying the technology they conducted sizing tests using the thin client technology. Motivation for sizing at Telkom is the need to understand how the various applications that they use affect the server and network resources. This information is required in order to be able to correctly predict resource usage, which applications are capable of working together, which applications require specific configurations, and which applications require their own dedicated resources.

A suite of standard and well-known applications that are commonly used in industry and in education were selected so as to see how they behave in the thin client environment.

6.2.1 Tests Procedures

The sizing methodology that was followed at Telkom is divided into two parts. First, a performance baseline for the server is established. This involves running the server for a period of time with no applications running on the server or clients requesting services, and thereby measuring the average “no-load” performance. This baseline is a reference point from which all other measurements will be measured against when the server is on load. Table 6.1 shows objects for which counters have to be quantified. A description of each counter is also provided with recommended average values where applicable. This table is used for both the initial performance baseline and the subsequent measurements when server is on-load. The results of the each test are documented in the Appendices E, F, G, and H.

Secondly, the performance of the server while on-load is measured for the different applications, and the measurements are documented in an application-sizing sheet. In addition to the objects in table 6.1, for which counters have to be monitored, the objects in Table 6.2 have to be added and their counters gauged. The objects in Table 6.2 are only applied and measured when the server is on load. For the most of the tested applications, the measurements are done for one user and for five users.

Object	Counter	**Description**
System	%Total Processor Time	Measure of total amount of processor activity (divided by number of processors)
System	Processor Queue length	Amount of threads in the CPU queue. All processors use a single queue. Once a CPU is available, the thread is switched onto that CPU. – ***Not more than 2 sustained.***
System	Context Switches/Sec	Rate at which the processors switch between different threads. ***Average 500.***
Processor	%Processor Time	Percentage time the CPU was executing a thread other than the Idle thread. Check that each CPU is being used by the application. - ***Less than 80% sustained.***
Processor	Total Interrupts/sec	Rate at which the CPU is receiving and servicing hardware interrupts. – ***Average 100***
Memory	Available Bytes	Amount of virtual memory available for use.
Memory	Committed Bytes	Amount of memory committed to all the processes running on the system.
Memory	Page Faults/sec	When a process refers to a virtual memory page that is not in its Working Set in main memory. It may be in the Standby List, (memory released by a process) in main memory and hence may not need to be fetched from disk.
Memory	Pages/sec	Number of pages read from disk or written to disk to resolve references to memory that were not in memory at the time of reference. - ***Average 20.***
Network Interface	Total Bytes Received/sec	Amount of bytes received per second on a network interface.
Network Interface	Total Frames Received/sec	Amount of frames received per second on a network interface.

Table 6.1 Objects to Measure Source: (Telkom, 2000)

Object	**Counter**	Description
User	Working Set	Amount of virtual memory allocated to all processes used by a specific user.
User	Working Set Peak	Highest value of the Working Set for a particular session.

Table 6.2 Additional objects to measured (Source: Telkom, 2000)

The actual resource usage and the impact on the server can be determined by comparing the performance before an application is used i.e. performance baseline, and while the application is being used i.e. server on load. This process is repeated for each application to be tested. The performance baseline, i.e. the performance before an application is used, is denoted by “0 users” in the application sizing sheets in appendices. The tests are carried out for 0,1, and 5 users on each application.

6.2.2 Sizing equipment

Various hardware and software components were used in the sizing of the different applications. The same components were used for all the various applications that were being investigated. The testing was carried out at the Telkom IT Data Center in Pretoria, South Africa.

1. **Sizing Hardware**

   The following hardware components were used:

   I. Server level

   A server farm with 4x Pentium III Zeon 500Mhz (2048 KB cache) with 4 gigabyte of RAM, and 4 X 18.2 GB hard disks (Raid 5).

II. Client level

Intel Pentium III PCs were used as client devices. The client devices were on a local area network (LAN) running at 100 Mbps (half duplex).

2. Sizing Software

The following software was used:

I. Server level

Microsoft Windows NT Terminal Server Edition with Terminal Server Service 5, Citrix MetaFrame version 1.8.
Different application software, depending on the specific one to be tested, was installed on the server.

II. Client level

The clients connect to a Citrix MetaFrame server via Citrix Program Neighborhood (ICA client software) version 4.20.715.
All clients connected on 800x600 video mode, 256 colors.

3. Notes and conditions

The following points should be noted about the tests that were carried out in the Telkom case study:

- It is important to note that the results should be regarded as general guidelines, developed using very specific applications scenarios and controlled testing processes.

- Results in other environments will very likely vary, depending on the following three factors:
  1) The type of hardware that is being used (server, clients, and network),
  2) The type and version of application being run, and
  3) The activity level of the users in that environment.
- It is also critical to note that performance requirements are by nature subjective, and therefore a measured latency may be perceived differently between organisations or individuals. For example, a measured value of latency in the educational environment may not be as critical as it would be in an engineering environment.
- Thorough testing in the actual environment where the technology is to be deployed is the best way to effectively measure how many users the technology will support.

6.2.3 Activities and Results Analysis

The empirical results for the four applications that were tested are documented in Appendices E – H. The different applications that were tested produce different behaviours, which are as follows:

I. <u>Microsoft PowerPoint 97</u>

- Microsoft PowerPoint 97 is a presentation application, which is part of the Microsoft Office Suite. This version of PowerPoint is a standard application used in Telkom S.A.
- The recommended default installation of the application was performed on the server.
- Appendix E contains the results of the tests in an application-sizing sheet.

User Scenarios

- Monitoring this application included, as stated before, monitoring without any activity (zero users) and monitoring the application in activity with one, five and ten users. PowerPoint is the only application test that has been performed for ten users.
- Application activities included creating, opening, saving, printing, editing files and other application activity.

Analysis and comments

- Application load depends on the size and contents of the documents.
- Application performance depends on the level of mouse and keyboard activity.
- The load on the processors was distributed equally and did not dominate a single processor at any one specific time.
- The application response was extremely quick on startup and whilst working with the actual application on terminal server.

Recommendation

This application is suitable for use on Terminal Server.

II. Novell Groupwise 5.5

- Novell GroupWise is a mailing system, which is a standard used by Telkom SA.
- The default installation was used on the server.
- Appendix F contains the results of the tests in an application-sizing sheet.

User Scenarios

- Monitoring this application included monitoring with zero, one, and five users.
- Application activities included creating, opening, saving, printing, editing electronic mails and other application activity.

Analysis and comments

- Application load depends on the size and contents of the documents.
- Application performance depends on the level of mouse and keyboard activity.
- The application response on startup and while working with the application was extremely slow.

Recommendation

This application is suitable for use on Terminal Server although, due to the load, the response was slow. It is recommended that this application should be placed on its own node and have minimal amount of users connecting to the servers. This would reduce performance degradation of the server.

III. Microsoft Excel 97

- Microsoft Excel 97 is a spreadsheet application.
- The default installation was performed on the server
- The results of the test for the application are available on an application-sizing sheet in Appendix G.

User Scenarios

- Monitoring this application was done for zero, one and five users.
- Application activities included creating, opening, saving, printing, editing files and other application activity.

Analysis and comments

- Application load depends on the size and contents of the documents.
- Application performance depends on the level of mouse and keyboard activity.
- This application works well on terminal server.

Recommendation

This application is suitable for use on Terminal Server.

IV. Microsoft Project 98

- Microsoft Project is an application for managing projects. This application is the standard program used for managing projects at Telkom S.A.
- The default installation was carried out on the server.
- Appendix H contains the results of MS Project tests on an application-sizing sheet.

User Scenarios

- Monitoring was done for zero, one and five users.
- During application activities files were opened, closed, edited, saved and printed.

Analysis and comments

- Load depends largely on the file sizes worked on, the type of contents as well as the speed of the client's keyboard and mouse activities.
- MS Project put quite a heavy load on the server as attested by the results on the application-sizing sheet in Appendix H.
- Connecting to the server was reasonably fast, and application response was good.

Recommendation

Although Microsoft Project puts a heavy load on the server, the application is suitable for use in the Terminal Server environment. It is recommended that the application should be used with caution in the Terminal Server environment.

6.3 Tolly Group Performance Research

Citrix commissioned the Tolly Group to evaluate the performance and scalability of the Citrix WinFrame (version 1.6) application server when supporting clients running 32-bit Windows applications. In one of the tests, the Tolly Group measured the time required for a Windows 95 client using a 28.8 Kbps modem connection to complete some common Microsoft Excel tasks when an increasing number of LAN clients were running on the WinFrame server (Kanter, 1998).

The results of this test showed that up to a total of 29 LAN clients and the 1 WAN client connected over the 28.8 Kbps modem could run Microsoft Excel from one dual-processor Pentium 90 WinFrame server without significant degradation. According to the report, the WAN client took about 30 seconds to perform a group of common Excel tasks with no other clients accessing the WinFrame server. When 19 LAN clients were added and simultaneously accessing the WinFrame server, the WAN client's response time in Excel was degraded by less than 10 percent. When the client base was increased to 29 LAN clients simultaneously accessing the server, the response time on the dial-up WAN client was degraded by less than 35 percent (Kanter, 1998).

When the Tolly Group benchmarked the average throughput between the WinFrame server and its thin clients using Citrix's ICA thin client server technology, they came to a conclusion that the ICA was a bandwidth-efficient technology, because it uses an average of only 12.9 Kbps between the WinFrame server and the ICA thin client (Kanter, 1998).

6.4 Hardware Recommendations

Table 6.3 shows the recommended number of users per processor type according to the type of users ranging from light to heavy users (Mathers, 2000). High school learners who are not acquainted with the use of computers and using fairly low bandwidth intensive applications can be classified as light to medium users and therefore the relevant columns for this analysis will range from a minimum of the medium users column value to a maximum of the light users value for a particular processor type.

Processor Type	Light Users	Medium Users	Heavy Users
Pentium Pro 200	35	25	13
Pentium II 300	45	30	18
Pentium III 500	60	40	23

Table 6.3 Average Supported Users per Processor (Mathers, 2000)

6.5 Number of users on a LAN

Latency is an important issue to consider when dealing with thin clients. As mentioned in Chapter 4, the Citrix ICA thin client technology saves on bandwidth by sending only mouse clicks and keyboard strokes to the server and then receiving screen updates on the client's screen. A high latency would result in performance degradation, because the user’s activities and operations on the client’s side would be delayed to appear on the user’s screen, thereby causing screen updates that are sluggish in relation to the mouse and keyboard input from the user.

In order to avoid latency, the average utilization on the network should be kept less than 30 percent (Mathers, 2000). The formula for calculating the number of client nodes on a LAN is:

C = (B/A) * P (Mathers, 2000)

where, C = Number of client nodes

B = Total bandwidth available (Kbps)

A = Average utilization per node (Kbps/client)

P = Percentage utilization cap

By using the Tolly Group’s average bandwidth consumption per client of 12.9Kbps and the 30 percent average utilization cap, we can calculate the number of thin client nodes that can be on a LAN segment.

For a 10Mbps Ethernet LAN, which is reasonably affordable and feasible for an underdeveloped rural school, the theoretical number of nodes, C that can be possible is:

C = (10 000 Kbps/12.9 Kbps/client) * 30/100 = 232 clients

Theoretically there could be around 230 clients on a thin client LAN. This number far exceeds the common practical maximum number of nodes on a single Ethernet segment. The feasible number of nodes in a school LAN is the same as the number of students in the classroom, which is assumed to be around 45 or more in overpopulated areas. The number of 45 nodes is well within the maximum number allowed in the thin client LAN with the above assumed parameters.

6.6 Applications to Avoid

1. Multimedia

The tests, the performance research, and bandwidth utilization calculations for applications in the above mentioned scenarios do not take into account the use of multimedia. Although the Citrix thin client technology supports sound when the client device has a sound card installed, it is recommended that, “applications that use sound and animation are generally not suited to this architecture” (Telkom, 2001). This depends on the actual application under consideration, and will have to be tested first. The reason for the architecture’s inability to fully address multimedia content is because animation and sound files generally generate extra network traffic and are bandwidth intensive applications. As stated before, the average bandwidth consumption per client is around 13 Kbps, and networked multimedia content applications would need far more than that to run effectively. For example, to listen to a radio broadcast stream over the Internet, using the freely available Windows Media Player 7 requires an average 20 Kbps of bandwidth. The 20Kbps bandwidth consumption is without any video, and adding visual content would further increase the bandwidth requirements.

Multimedia also puts a heavy burden on the server, because a higher memory for each session address space would have to be allocated for each of the users running multimedia applications concurrently. This would put a lot of load on the processor in terms of the system overhead, and consequently degrade the server performance.

As has been stated in Chapter 3, multimedia enriches the learning experience by providing a multi-modal learning environment through a combination of text, graphics, video, animation and sound. This has a positive effect on the learning experience of the learner and for this reason multimedia is a desirable component for an effective learning experience.

Although multimedia is a desirable component for effective delivery of educational content, it is not the paramount requirement for effective learning. According to a research thesis on “Information Communication Technologies To Enhance Teaching and Learning in Higher Education”, the top five most available and required types of software applications for teaching and learning at a particular South African university, in their order of usage are:

1. Word processors (91%)
2. Email (87%)
3. Web browsers (81%)
4. Spreadsheets (75%)
5. Presentation software (62%) (Mostert, 2000).

These figures reflected above are for a university environment, but this knowledge can be transferred into the high school environment. A university typically has more resources and money to spend on educational content provision using computers than would a rural school. If the university does not yet fully utilize multimedia for the delivery of educational content, it is not feasible that an underdeveloped rural school would be utilizing networked multimedia. A major reason that multimedia education has not been fully deployed in South African educational institutions is the amount of resources i.e. money, skill, bandwidth, and so on, which are needed for both the development of the content and its delivery.

2. <u>16 Bit applications</u>

The current windows operating systems including Windows NT, Windows 95 and later versions is a Win32 (32-bit) environment. Windows 3.x for DOS is a Win16 (16-bit) operating environment. The WinFrame architecture is based on a Win32 environment and therefore it inherently runs 32-bit applications more effectively than 16-bit applications. Windows NT runs Win16 applications through a process called WOW (Win16 on Win32), translating 16-bit applications in enhanced mode. This process causes Win16 applications to consume additional system resources, which reduces the number of users per processor by 20% and increases the memory required per user by 25% (Kanter, 1998). For this reason, the use of 16-bit applications should be avoided whenever possible when using thin clients. When using 16-bit applications the processor and memory requirements will have to be adjusted accordingly, thereby incurring more total costs of running the applications.

As time passes, this should pose less of a problem for schools, because most of the applications that are available today are 32-bit applications.

3. Printing across the network

Printing causes additional traffic on the network. Printer spool files are not encapsulated as part of the ICA session, and will utilize more bandwidth. In a rural school scenario printing would be one cost to control, as it is usually controlled in most universities, because users can easily abuse this service. Effectively there would have to be some control of who prints what and how much. The easiest way to do this would be to have the printer in a central location whereby the access to the printing services is controlled. This would conceivably be near to the Terminal server or wherever the administration of the network is situated.

One way to control the printing service and counteract the bandwidth problem at the same time is to have the printer attached to the server on a local parallel port. In this configuration, print jobs will not need to traverse the network, and at the same time will be controlled by the administrator. The connection between the printer and the parallel interface is of high bandwidth and therefore the printing would be done as soon as the user has gained access.

4. Splash screens

A splash screen consists of animated graphics and sounds that entice the user for advertisement purposes. This is a bandwidth intensive application and, as mentioned above, will put an undesirable burden on the network resources.

6.7 Conclusion

The tests that have been done as part of the Telkom case study are evidence that the thin client terminal server is able to effectively host the widely used Microsoft applications for industry and educational use. The results that have been provided from the tests conducted at Telkom only offer a general indication of what might happen during the use of thin client technology when using the tested applications. These results are not conclusive because of the conditions that they have been carried out under. The equipment that has been used for testing is high-end equipment, with very high specifications. The amount of memory used and the processing power in the server is excessively disproportionate in comparison with the number of users that the experiments have been undertaken. The maximum number of users, which is five for most experiments, barely affects the performance of the server. More precise analysis of the server's behavior would have been detected when the number of users gets high enough to use up all of the memory and the processing power. As mentioned before, the tests can only be used as a general indication of the fact that the tested applications are suitable for deployment in the thin client environment.

The applications that have been tested in this chapter are commonly used applications and are also in the top five list of most used software in the educational environment. Those that have not been tested but appear in the list are software applications that are in the same league as the ones that have been tested and therefore would be expected to behave in a similar manner in the thin client environment. The next chapter looks at an overall recommendation concerning the deployment of thin clients for the delivery of education in a rural and underdeveloped setting.

Chapter 7

Overall Conclusions and Recommendations

7.1 Is thin client a viable solution?

The previous chapters have discussed the needs for effective delivery of education in a rural high school setting, and a possible technology to provide for this has been proposed. The proposed technology's cost-effectiveness has been evaluated in terms of its ability to deliver the required functionality, and in terms of its ability to offer competitive pricing in comparison to other technologies that can deliver educational content with more or less the same effect.

The most important factors that are necessary for the effective delivery of educational content in a rural setting have been addressed in this study. These factors are interactivity, control, and richness of media. The main aim of this research is to find a cost-effective means of addressing the problem of low quality education, which is an unfortunate feature of the deployment area.

Based upon an analysis of the functional needs of learners in terms of content delivery, thin client technology is able to support two of the three criteria identified i.e. self-controlled learning, and interactivity.

In terms of cost and technical performance, our formal models and field trial within an industry setting have suggested that:

1. The cost of thin client deployment within a rural school setting will be lower than rival technologies when the long-term cost of ownership is factored in with the cost of deployment.
2. This proposed solution meets the technology demands of current computer based learning activities within schools as outlined in chapter 6, but improvements to

the technology are needed if the future demands of multimedia computer based training is to be adequately met. The multimedia demand was the 3rd major criteria identified as a functional need of learners. This is discussed further in section 7.2.

The remainder of this chapter focuses on how additional value can be obtained through the use of the proposed thin client technology in the delivery of educational content. The value is discussed in terms of the opportunities that can be reaped in the case of deploying the thin client technology in the envisaged deployment area. The shortfalls of the technology are discussed and a way of addressing these shortfalls is suggested. Also, recommendations for future investigations within the delivery of educational content using thin client technology are proposed.

7.2 Shortfalls of Thin Clients

As has been outlined in the previous chapter, the present thin client technology lacks the ability to cope with multimedia content. The reason for this is that multimedia applications are very bandwidth intensive applications that cannot be handled by ICA, which is a low bandwidth communications protocol used in Citrix thin clients. This inability disadvantages the learners because multimedia is a desirable component in the delivery of educational content for effective learning. In order to cater for multimedia content, Citrix has developed VideoFrame multimedia server software. Citrix VideoFrame is an extension to, and works with, the Citrix WinFrame or MetaFrame, and offers to efficiently integrate, manage, publish and maintain audio and video content to ICA clients. It is advised that Citrix WinFrame and Citrix VideoFrame should not be installed in the same hardware. MetaFrame and WinFrame can be configured to launch VideoFrame-based content, which means that lessons in the WinFrame server can be integrated with multimedia content in the VideoFrame server thereby adding more value to the lesson content delivery.

7.3 Further Opportunities in the deployment of Thin Clients

The physical design of the thin client station has some attributes that have been stated in chapter 4, which offer further opportunities in the case of deployment of thin client technology to the given deployment situation. The robust nature of the concealed tamper-resistant casing of a pure thin client design makes it resistant to school going children who might spill undesirable elements like cool drinks or snacks into the air ventilators of the system. This happens quite a lot in various computer laboratories in educational institutions, and it is a considerable source of damage to computer systems. The design of the thin client user station is such that even when dirt is spilled over the system it can be simply wiped off without damaging the delicate functional parts inside the casing.

The fact that the thin client technology has its functional operation centralized at the server implies that the user station is completely useless on its own i.e. it cannot function when it is detached from the network. This reduces its value when the device is pulled out of the network. This attribute makes the device less susceptible to being stolen, as it will be of no use when detached from the network. Since computers have a high value and are a desirable commodity, they are very vulnerable to theft. In a rural area where physical security might not be up to standard, using fat client desktop computers would be a very risky investment, because the desktops can be used as stand-alone PCs.

Centralized management also has a positive effect on the scalability of the thin client solution. Adding more users to the network can be done without impacting other users, and with less effort from the administrator. Adding more servers is also a seamless job that will be transparent to the users.

A pure thin client user station has no moving parts inside the device, which implies that there is less power consumed by the device as compared to its fat counterpart. This quality would imply a saving on electrical bills over a long period, thereby positively affecting the TCO even further. In rural areas, the power supply is often not as reliable as in the urban areas. Power surges and total power cuts are frequent. A practical solution for this would be to use a Universal Power Supply (UPS) for power backup, so that there is no loss of data in the volatile memory. In the thin client scenario there would be a need for only one UPS for backing up the server, because that is where all data resides. In the fat client scenario there would be a need for UPS support for all network stations to prevent loss of data during power failures. Again, this would be a positive contribution towards the thin clients' TCO.

The shadowing feature in thin clients gives a remote administrator the ability to control and view any user's activity remotely. In a scenario whereby the school LAN is connected to a public or private WAN, this reduces costs by providing support from remote support personnel to the user without having to be physically present in the user's environment. This is of great significance to the deployment situation in this study because a support and maintenance personnel would take a long time to reach the area due to the remoteness of the area. This tool is also invaluable for the instructor because ICA clients who have been specifically assigned the necessary rights can view other users' video, mouse clicks and keyboard strokes as if they were infront of the viewed user's station. This gives the instructor the ability to monitor the students' activities and participation in class assignments and also offer assistance where necessary. The shadowing system tool enables the instructor to monitor the engagement of the students to the lesson content.

The ability to reuse existing equipment will save more money and contribute to an even further reduction in the total cost of ownership. Underprivileged schools, at various locations in South Africa have a lot of old PCs that are donated by industrial companies who are upgrading to more powerful machines in exchange for a good name and reputation in the school communities. These machines end up being useless and abandoned, because it costs the schools more money to maintain them as they have outdated abilities and specifications that are not compatible with the current operating systems. Since the thin client environment is platform-independent, these old machines could be reconfigured as thin clients and subsequently put to beneficial use in the thin client environment. The machines' obsolescence does not matter as much in the thin client environment because processing and storage take place at the server. A school that has old PCs can extend the lifetime of those PCs by reconfiguring them and using them as thin clients, thereby saving on the costs of hardware acquisition and extending the lifetime of the existing PCs, which will have a direct influence on the TCO. The thin client's independence from operating system and client station abilities makes it possible to deploy the technology in a piecemeal approach as in the Telkom example in Chapter 5. Telkom's strategy in deploying the thin client technology is in step-by-step form starting from a hybrid network compromising of more fat clients than thin clients to one that has more thin clients than fat clients. This scenario is more realistic for a rural and underdeveloped school whereby the existing PC computers, if any, would be integrated into the solution instead of being discarded. Of course, thin clients implemented in this way do not have the robust qualities of pure thin client workstations.

Application Service Providers (ASPs) are third-party entities that manage and distribute software-based services and solutions to customers across a wide area network from a central data center. ASPs are business ventures that are emerging throughout the world and they have the potential to be as popular as Internet Service Providers (ISPs) in the near future. The ASP solution would be complementary to the thin client solution. Since the high school syllabus is uniform for all schools in South Africa, a number of schools with fat or thin client LAN networks can have their content hosted by an ASP and access the data over a WAN. In essence, each school can choose to outsource some or all aspects of their information technology needs through an ASP. This would remove the burden of hosting applications and the maintenance of the hosting server away from each individual school thereby further reducing the TCO.

Another advantage for the Citrix thin client solution is that the company has presence in South Africa. This makes it easy for administrators to contact the company when in need of technical support. The support for Citrix products is available through Citrix Partners that employ engineers and Certified Citrix Administrators (CCA) and Certified Citrix Enterprise Administrators (CCEA). If Citrix engineers and administrators cannot solve the problem locally it is then escalated to Citrix UK in the United Kingdom. Citrix also has an office in South Africa.

7.4 Suggestions and Guidelines for Further Research

This research has concentrated on the evaluation of the thin client technology as a cost-effective delivery for educational content. The thin client technology is a relatively new technology that has not been widely used. There are various fields of research that can be pursued including the cost-effectiveness of the VideoFrame server software in the delivery of multimedia rich content for the purpose of education in bandwidth-stricken networks. Other research that is vital is the investigation of deploying the thin client technology over a WAN with many schools attached to the WAN and accessing the same applications and data. The use of ASPs would be complimentary to the WAN access investigation.

This study has not researched the platforms and applications that can be used for the distribution of educational content. Nowadays, the Internet is widely used as the platform of choice for the delivery of education for both industrial training and formal education. The reason for this is because the Internet is an open system that is accessible to millions of people all over the world and it offers cost-effective means of communications. It is also an enormous source of information and learning resources. Like the Internet itself, web-based education is an open system of education that is not confined to the classroom and predetermined structures e.g. books, CD-ROMs, and so on. Education that is delivered via the Internet is specifically called Online Learning. An Integrated Distributed Learning Environment (IDLE) is a learning platform that combines the collaboration tools of the Internet with the World Wide Web access to form a user-friendly application for education and training. IDLEs promote collaborative learning through the use of both synchronous and asynchronous communications tools, e.g. chat rooms and e-mail. IDLEs are accessible through any popular web browser. There are various types of IDLEs with various features, ranging from chat rooms to content development tools, but they all have the main goal of enabling the users' learning experience to be as simple as possible. They also provide online assessment so as to check on the student’s comprehension of the material. A study to investigate the most appropriate IDLE with an interface that is suitable for the envisaged deployment area would be complementary to this study.

7.5 Scope Limitations of Study

The investigations contained in this research have some limitations as far as their precision is concerned, although the findings are reliable in general terms. This limitation is due to the fact that the proposed solution has not been implemented and tested for the purpose of educational content delivery in the envisaged deployment area. This would require a lot of money and time, which are not within the reach of this investigation. The research relies heavily on scenarios and tests that have been conducted by commercial companies within their capacity and applicability as industrial firms. The only way to fully ascertain the true effects of utilizing a thin client network in a rural and underdeveloped area is through actual implementation of the technology, and then evaluation of the outcomes.

The results that have been used from the tests conducted in the industrial company are also limited, because these results only offer a broad suggestion of what might happen during the deployment of thin client technology, due to the conditions that the tests have been performed under. The equipment that has been used for testing is extreme high-end equipment, with very high specifications and an excessively disproportionate amount of server memory and processing power when compared to the small number of users that the experiments have been carried out with.

Despite the limitations in precision, this thesis provides a clear general indication of what will happen in a thin client deployment within a rural high school setting.

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APPENDIX A-1

TCA totals for the entire 2 500 clients

Source: (Tolly Group, 1999)

Application Cost Element	Application Deployment Model Totals		
	Traditional Desktop Comparison	**Customer-Defined Model / Environment**	**Citrix ICA Client Comparison**
INITIAL COSTS			
Application Development	$ 31 982	$ 31 982	$ 31 982
Client Software Acquisition	$ 1 077 500	$ 1 077 500	$ 605 000
Server Software Acquisition	$ 384 078	$ 386 166	$ 1 309 836
Application Integration	$ 4 898	$ 9 110	$ 2 569
Application Installation	$ 159 725	$ 68 450	$ -
Application Training	$ 4 013 548	$ 4 013 548	$ 4 013 548
Hardware Procurement	$ 1 727 380	$ 1 766 300	$ 2 436 922
WAN Network Hardware Infrastructure	$ 360 000	$ 3 006 000	$ 511 200
Initial Cost Totals	*$* ***7 759 111***	*$ 10 359 056*	*$* ***8 911 056***
RECURRING COST IN YEARS 1 THRU 4			
WAN Network Usage	$ 547 022	$ 2 972 900	$ 624 827
LAN Network Infrastructure	$ 412 500	$ 412 500	$ 412 500
Application Maintenance	$ 4 690 675	$ 3 869 175	$ 3 047 675
Server Operations	$ 60 686	$ 64 580	$ 131 678
Technical Support	$ 3 327 032	$ 1 835 726	$ 1 090 073
Loss of Productivity	$ 10 141 250	$ 5 090 908	$ 3 062 658
Building Infrastructure	$ 291 400	$ 291 400	$ 291 400
Recurring Cost Totals	*$* ***19 470 565***	*$ 14 537 189*	*$* ***8 660 811***

APPENDIX A-2(Amended version of appendix A-1)

TCA totals for the entire 2 500 clients

Source: (Tolly Group, 1999)

Application Cost Element	Application Deployment Model Totals			
	Traditional Desktop Comparison		Citrix ICA Client Comparison	
INITIAL COSTS				
Client Software Acquisition	$	1 077 500	$	605 000
Server Software Acquisition	$	384 078	$	1 309 836
Application Integration	$	4 898	$	2 569
Application Installation	$	159 725	$	-
Hardware Procurement	$	1 727 380	$	2 436 922
Initial Cost Totals	***$***	***3 353 581***	***$***	***4 354 327***
RECURRING COST IN YEARS 1 THRU 4				
Application Maintenance	$	4 690 675	$	3 047 675
Server Operations	$	60 686	$	131 678
Technical Support	$	3 327 032	$	1 090 073
Loss of Productivity	$	10 141 250	$	3 062 658
Recurring Cost Totals	***$***	***18 219 643***	***$***	***7 332 084***

APPENDIX B-1

TCA application deployment model per client

Source: (Tolly Group, 1999)

Application Cost Element	Application Deployment Model By Client		
	Traditional Desktop Comparison	**Customer-Defined Model / Environment**	**Citrix ICA Client Comparison**
INITIAL COSTS			
Application Development	$ 13	$ 13	$ 13
Client Software Acquisition	$ 431	$ 431	$ 242
Server Software Acquisition	$ 154	$ 154	$ 524
Application Integration	$ 2	$ 4	$ 1
Application Installation	$ 64	$ 27	$ -
Application Training	$ 1 605	$ 1 605	$ 1 605
Hardware Procurement	$ 691	$ 707	$ 975
WAN Network Hardware Infrastructure	$ 144	$ 1 202	$ 204
Initial Cost Totals	*$* ***3 104***	*$ 4 144*	*$* ***3 564***
RECURRING COST IN YEARS 1 THRU 4			
WAN Network Usage	$ 219	$ 1 189	$ 250
LAN Network Infrastructure	$ 165	$ 165	$ 165
Application Maintenance	$ 1 876	$ 1 548	$ 1 219
Server Operations	$ 24	$ 26	$ 53
Technical Support	$ 1 331	$ 734	$ 436
Loss of Productivity	$ 4 057	$ 2 036	$ 1 225
Building Infrastructure	$ 117	$ 117	$ 117
Recurring Cost Totals	*$* ***7 788***	*$ 5 815*	*$* ***3 464***

APPENDIX B-2(Amended version of appendix B-1)

TCA application deployment model per client

Source: (Tolly Group, 1999)

Application Cost Element	**Application Deployment Model by Client**	
	Traditional Desktop Comparison	**Citrix ICA Client Comparison**
INITIAL COSTS		
Client Software Acquisition	$ 431	$ 242
Server Software Acquisition	$ 154	$ 524
Application Integration	$ 2	$ 1
Application Installation	$ 64	$ -
Hardware Procument	$ 691	$ 975
Initial Cost Totals	***$ 1 342***	***$ 1 742***
RECURRING COST IN YEARS 1 THRU 4		
Application Maintenance	$ 1 876	$ 1 219
Server Operations	$ 24	$ 53
Technical Support	$ 1 331	$ 436
Loss of Productivity	$ 4 057	$ 1 225
Recurring Cost Totals	***$ 7 228***	***$ 2 933***

APPENDIX C

Different costs for different WBT/PC mixes

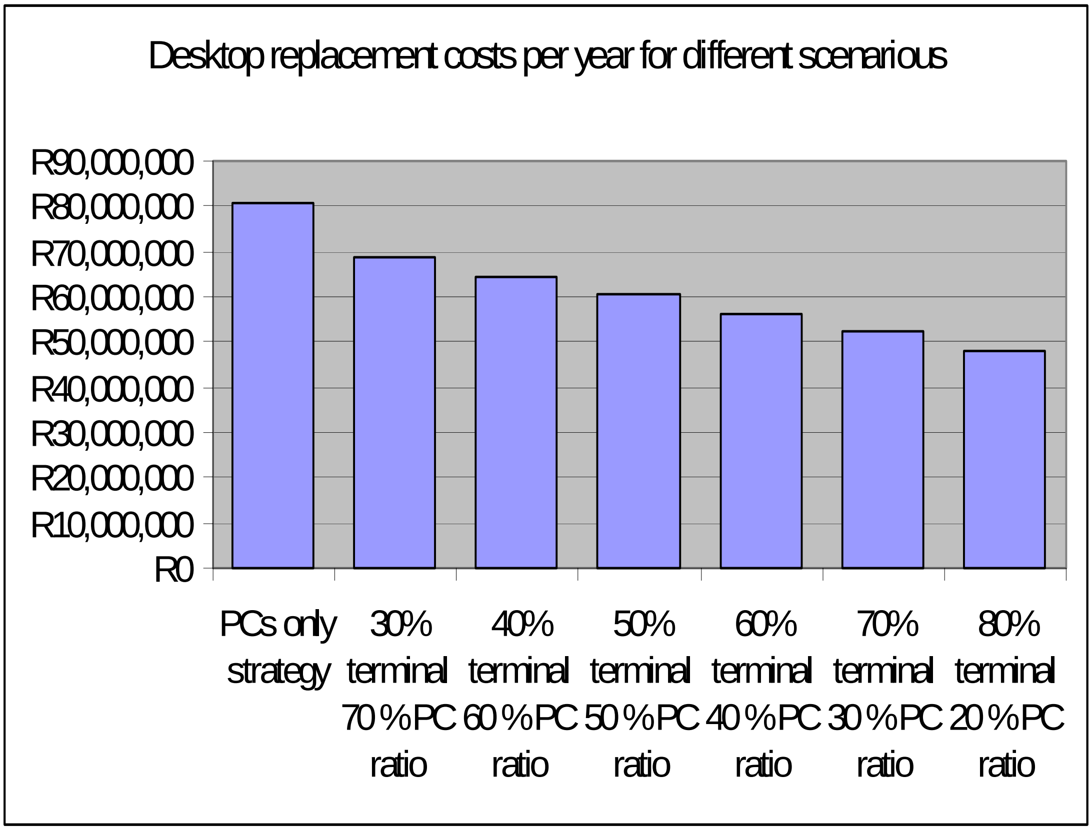
Source: (Telkom, 1999)

Desktop strategy to be followed	Replacement cost per year
PCs only strategy	R81 000 000
30% WBT : 70% PC ratio	R68 687 100
40% WBT : 60% PC ratio	R64 582 800
50% WBT : 50% PC ratio	R60 478 500
60% WBT : 40% PC ratio	R56 374 200
70% WBT : 30% PC ratio	R52 269 900
80% WBT : 20% PC ratio	R48 165 600

APPENDIX D

Graphical Presentation of WBT/PC mixes

Source: (Telkom, 1999)



APPENDIX E

Test results for Microsoft PowerPoint Application   Source: (Telkom, 2000)

Object: System					
	Application	PowerPoint			
	Date	Date: 5/11/2000			
	Sized on	Reported on \\TPHQ-WSTS07			
Object: System		0 Users	1 User	5 Users	10 Users
	% Total Processor Time	0	0.768	2.369	2.828
	Processor Queue Length	0	0	0	2434.009
	Context Switches/sec	0	950.816	2681.412	0
Object: Processor (All four processors)	(sum>)	0 Users	1 User	5 Users	10 Users
	% Privileged Time	0	2.164	6.401	6.608
	% Processor Time	0	3.073	9.477	11.311
	Interrupts/sec	0	297.852	382.345	340.933
Object: Memory		0 Users	1 User	5 Users	10 Users
	Available Megabytes	0.0	3,905.0	3,870.7	3,779.4
	Committed Megabytes	0.0	71.9	137.5	368.7
	Page Faults/sec	0.0	48.1	122.7	377.6
	Pages/sec	0.0	7.8	7.8	35.3
Object: Network Segment (All users)		0 Users	1 User	5 Users	10 User
	Total bytes received/second	0	4860.71	19183.836	8.72
	Total frames received/second	0	33.511	117.005	17.441
Object: Paging File (All Users)		0 User	1 User	5 Users	10 Users
	% Usage	0	0.23	0.18	0.28
	% Usage Peak	0	0.28	0.28	0.49
Object: User (All Users)	(Sum>)	0 User	1 User	5 Users	10 Users
	% Privileged Time	0	0.124	0.456	0.339
	Page Faults/sec	0	13.533	47.5	135.862
	Thread Count	0	38	183	408
	Virtual Bytes	0	221126656	1115578368	4307959808
	Working Set	0	22749184	78233600	251990016
	Working Set Peak	0	27615232	131067904	527593472

APPENDIX F

Test results for Novell Groupwise Application Source: (Telkom, 2000)

Object: System				
	Application	Groupwise 5.5		
	Date	Date: 5/11/00		
	Sized on	Reported on \\TCEN-WTS-NODES		
Object: System		0 Users	1 User	5 Users
	% Total Processor Time	0	2.013	2.184
	Processor Queue Length	0	1634.956	2337.209
	Context Switches/sec	0	0	0
Object: Processor (All four processors)	(sum>)	0 Users	1 User	5 Users
	% Privileged Time	0	5.926	5.729
	% Processor Time	0	8.051	8.738
	Interrupts/sec	0	336.764	410.92
Object: Memory		0 Users	1 User	5 Users
	Available Megabytes	0.0	3,849.1	3,842.7
	Committed Megabytes	0.0	176.1	187.6
	Page Faults/sec	0.0	211.0	120.3
	Pages/sec	0.0	7.4	21.
Object: Network Segment (All users)		0 Users	1 User	5 Users
	Total bytes received/second	0	8368.83	29966.031
	Total frames received/second	0	60.553	152.398
Object: Paging File (All Users)		0 User	1 User	5 Users
	% Usage	0	0.15	0.17
	% Usage Peak	0	0.37	0.34
Object: User (All Users)	(Sum>)	0 User	1 User	5 Users
	% Privileged Time	0	0.046	0.296
	Page Faults/sec	0	10.645	32.064
	Thread Count	0	43	240
	Virtual Bytes	0	373067776	2025693184
	Working Set	0	15183872	134905856
	Working Set Peak	0	33689600	194453504

APPENDIX G

Test results for the Microsoft Excel 97 Application Source: (Telkom, 2000)

Object: System		
	Application	Microsotf Excel 97
	Date	Date: 5/6/00
	Sized on	Reported on \\TCEN-WTS-TSL1

Object: System		0 Users	1 User	5 Users
	% Total Processor Time	0.016	1.515	2.731
	Processor Queue Length	0	842.537	2873.69
	Context Switches/sec	376.406	0	0

Object: Processor (All four processors)	(sum>)	0 Users	1 User	5 Users
	% Privileged Time	0.052	3.706	8.469
	% Processor Time	0.064	6.058	10.925
	Interrupts/sec	262.87	336.395	385.519

Object: Memory		0 Users	1 User	5 Users
	Available Megabytes	3,921.4	3,904.2	3,879.0
	Committed Megabytes	53.1	84.0	136.4
	Page Faults/sec	10.1	112.3	151.1
	Pages/sec	0.0	2.9	7.7

Object: Network Segment (All users)		0 Users	1 User	5 Users
	Total bytes received/second	85.736	0	0
	Total frames received/second	0.967	0	0

Object: Paging File (All Users)		0 User	1 User	5 Users
	% Usage	0.18	0.26	0.18
	% Usage Peak	0.21	0.29	0.30

Object: User (All Users)	(Sum>)	0 User	1 User	5 Users
	% Privileged Time	99.985	0.137	0.67
	Page Faults/sec	7.554	51.112	57.008
	Thread Count	197	36	174
	Virtual Bytes	691441664	233246720	1098399744
	Working Set	49303552	25616384	89030656
	Working Set Peak	60657664	28999680	130711552

APPENDIX H

Test results for the Microsoft Project 98 Application   Source: (Telkom, 2000)

Object: System				
	Application	MS Project 98		
	Date	Date: 5/12/2000		
	Sized on	Reported on \\TPHQ-WS-TS07		
Object: System		0 Users	1 User	5 Users
	% Total Processor Time	0.011	0	2.378
	Processor Queue Length	0	0	0
	Context Switches/sec	377.148	0	2549.354
Object: Processor				
(All four processors)	(sum>)	0 Users	1 User	5 Users
	% Privileged Time	0.038	3.114	6.275
	% Processor Time	0.045	5.43	9.513
	Interrupts/sec	262.941	313.804	385.105
Object: Memory		0 Users	1 User	5 Users
	Available Megabytes	3,739.5	3,720.2	3,686.4
	Committed Megabytes	53.0	70.4	127.7
	Page Faults/sec	10.2	46.5	125.8
	Pages/sec	1.8	5.6	23.0
Object: Network Segment				
(All users)		0 Users	1 User	5 Users
	Total bytes received/second	195.6	6,907.4	19,840.3
	Total frames received/second	1.696	51.41	118.492
Object: Paging File				
(All Users)		0 User	1 User	5 Users
	% Usage	0.02	0.05	0.255
	% Usage Peak	0.02	0.05	0.258
Object: User				
(All Users)	(Sum>)	0 User	1 User	5 Users
	% Privileged Time	0	0.197	0.406
	Page Faults/sec	0	15.627	49.068
	Thread Count	0	37	185
	Virtual Megabytes	-	221.1	1,059.5
	Working Set (Megabyte)	-	23.3	86.8
	Working Set Peak (Megabyte)	-	29,784.0	128.3