THE DEVELOPMENT AND TESTING OF COMPUTER-AIDED TEACHING TOOLS - ADDRESSING THE CONCEPTUAL AND PRACTICAL DIFFICULTIES EXPERIENCED BY FIRST YEAR PHYSICS STUDENTS

by

BYREN MITCHEL ARCHARY

B. Sc. Hons. (Natal)

A thesis submitted in partial fulfilment
of the requirements for the degree of
Master of Science
in the School of Chemical and Physical Sciences
University of Natal

PIETERMARITZBURG

DECEMBER 2002

ACKNOWLEDGEMENTS

I wish to express my gratitude to all those people who assisted and encouraged me throughout this work. In particular:

To my supervisor, Dr Nithaya Chetty, I extend my heartfelt appreciation for his unwavering dedication and guidance that he has shown during this project and for the encouragement and advice which he so freely and frequently gave.

I am also indebted to my co-supervisor, Professor Diane Grayson, for her experience, insight and supervision throughout the course of this research.

I wish to express my deepest gratitude to my PULP volunteers for their commitment to this project. None of this could have been done without you guys and, this programme is as much mine as it is yours.

Finally to my parents Poovan and Sandra Archary, my brother Kelvin and sisters Abagail and Chanel for being my pillars of love, encouragement and guidance. Thank you for being my alarm clock and my checks on reality. Thank you for being my shelter and so tolerant of my tangent moods. I could not have completed this work without the support and love from all of you.

DECLARATION

I declare that this work is a result of my own research, except where specifically indicated to the contrary, and has not been submitted for any other degree or examination to any other university.

Signed: ______________________ Date: 26/03/03

I hereby certify that this statement is correct

______________________ 26/03/2003

Dr. N. Chetty
(SUPERVISOR)

ABSTRACT

There has been a great deal of research, both locally and abroad, conducted on the learning practices of students at school and at tertiary levels. In an attempt at improving the status of education, some educators have looked towards the use of computer-aided learning tools as a possible panacea for the discrepancy between what is being learnt and what is being taught in traditional educational environments.

The Physics Undergraduate Learning Programme (PULP), is a research-based instructional software package that tests the effectiveness of computers in physics education. The program was specifically designed to identify and address the difficulties experienced by first year introductory physics students enrolled at the School of Chemical and Physical Sciences at the University of Natal (Pietermaritzburg).

The research is based on an iterative process of assessment through tests and interviews, and subsequent modifications to the program. The results obtained from these methods of investigation are reported and this dissertation concludes with a discussion on the usefulness and limitations of computers in physics education.

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Overview

There has been a great deal of research, both locally and abroad, conducted on the learning practices of students at school and at tertiary levels. The importance of research into physics education has become so established that several journals have been devoted to publishing papers relating to the findings of physics education researchers, for example, "The Physics Teacher", published by the American Association of Physics Teachers, "Physics Education Research" which is a supplement published in the American Journal of Physics and the "South African Journal of Higher Education".

Universities have also formed physics education research groups aimed at identifying student difficulties and improving education by developing alternative teaching methods at their institutes. These include the "Center for Higher Education Development" (CHED) at the University of Cape Town, the "Research and Development in Mathematics, Science and Technology Education" (RADMASTE) at the University of Witwatersrand and the "Conceptual and Reasoning Difficulties in Science, Mathematics and Technology" (CARD) at the University of Natal, Pietermaritzburg. The "Center for the Improvement of Mathematics, Science and Technology Education" (CIMSTE) at the University of South Africa assists in the professional development of teachers, particularly at senior secondary school level as well as the improvement of teaching and learning at tertiary level.

The findings of numerous research initiatives conclude, in one form or another, that students hold strong preconceptions of physics principles long before they are introduced to them, even in their first lecture (Hendricks, 2002). Students' prior knowledge, social and economic backgrounds and their religious and cultural beliefs influence these preconceptions. It, in turn, influences how students interpret and organise the environment around them and how they structure their learning (Bransford *et al*, 2000). Further investigations show that students' preconceptions are resilient to change even after rigorous exposure to instruction (Grayson, 1996). This has lead to the realisation that in order for students to learn effectively, one needs to improve the way they think and the way they are taught, to promote conceptual change (Reif, 1986).

Some traditional lectures however do little to bring about conceptual change since the focus is still on the quantitative rather than the qualitative assessment of the students' understanding and ability (McDermott, 1993). Although many students do not attempt any physics courses higher than those offered at first year level, much of the syllabus is seemingly designed for the prospective professional physicist (Redish & Steinberg, 1999). A long-standing problem of traditional lectures is the high student to lecturer ratio that makes active involvement extremely difficult. As Meltzer & Manivannan (2000) state:

> *"Students do not absorb physics concepts simply by being told (or shown) that they are true, and they must be guided to resolve conceptual confusion through a process that maximises the active engagement of their mental faculties."*

In an attempt to reduce the discrepancy between what is being learnt and what is being taught, to promote conceptual changes and to increase the interaction between students and lecturers, some lecturers have included computers as an alternative method of instruction.

Computers have a seemingly limitless capacity to produce, store and retrieve data. They easily perform complicated algorithms and simulate experiments in the physics laboratory that would otherwise occur too quickly, too slowly or be either too dangerous or too expensive (Kozma, 1987). The recent advances in computer technology and computer programs, as well as the wealth of information that is readily available from the internet, makes the use of computers in physics a potentially useful medium for enhancing student learning (Fuller, 1986).

The role of the computer as a possible supplementary learning tool has resulted in a mass production of educational software programs. In an attempt to capture the students' attention and make their learning a valid experience, many software programs include text, audio effects and a combination of animation and video. These programs are not only designed for introductory physics courses but include higher levels of instruction as well and deal with topics that range from optics (Bason, 1990) to quantum mechanics (Visscher, 1990). Computers are also used in introductory physics laboratories to explore, amongst others, kinematics (Beichner *et al*, 1990) and electricity (Ronen *et al*, 1997). A detailed discussion on the role of computers in physics education is given later in this chapter.

Unfortunately, despite the teaching capacity computers promise to have, the "effectiveness and efficiency of teaching and learning remains low at most levels of education" (Reeves, 2000). Consequently, learners are left "drowning in information but starved of knowledge" (Long, 2001) and the general attitude of physics being both difficult and boring persists (Sillitto & MacKinnon, 2000). Ironically, it is the explicit focus on the technological capabilities of the computer that has been cited as a primary reason for its ineffectiveness (Erstad, 1998; Hargis, 2000). Programs that contain too much text are seen as glorified textbooks, whilst a program that focuses on animation and video is regarded as a computer game (Chabay & Sherwood, 1992). Although entertaining a student is important, it should not distract from the purpose of the computer program, which is to aid instruction and improve the students' understanding of and disposition towards physics. This leads to the theme of this dissertation.

The Physics Undergraduate Learning Programme (PULP) is a Masters' project initiated by the Physics programme of the School of Chemical and Physical Sciences at the University of Natal (Pietermaritzburg). The project tests the effectiveness of a computer-aided learning program as a supplement to current teaching practices. For the purposes of this project, a program was designed using the Macromedia® Authorware® programming language, which was endorsed and supported by the University's Information Technology in Higher Education Division (ITEd). PULP is aimed at first year introductory physics students and covers some of the topics included in the physics syllabus as well as simulating some of the experiments conducted in the laboratory. The topics chosen were based on conversations with lecturers involved with the teaching of first year physics and first year physics laboratory demonstrators, and the focus was on those sections that students traditionally found challenging.

Chapter 2 details the principles governing the development of an educational program and shows how these principles were used in the design of PULP. It discusses the need of a specialist task group consisting of a computer programmer, physics education researcher and a physics instructor. It shows how the use of text, graphics and animation may be used to enhance rather than dominate an educational program. A description of the Authorware programming language and the technical background of PULP is included in this chapter. Finally, a discussion of the students' use of the program and the methods of investigation employed during the research process is given as conclusion to this chapter.

Chapter 3 investigates the practical difficulties students have with basic measuring instruments that comprise the vernier calipers, micrometer screw gauge and the travelling microscope. Most students have little or no prior experience in the use of these instruments, which are used throughout the first year in many laboratory experiments. The chapter discusses the design and implementation of this section of the program and gives an analysis of the results of the two tests conducted on the students as a form of assessment. This chapter shows how the program was modified to promote conceptual change by first identifying the difficulties experienced by students in taking measurements from these instruments, and how these changes affected the results of the second assessment.

Chapter 4 describes the simulation of the refraction of light through a triangular prism and discusses optical concepts such as minimum deviation, symmetry and the refracting angle of the prism. The chapter begins by outlining previous research into students' understanding of physical and geometrical optics and describes how the program was designed to take congnisance of these difficulties. Students are given two tests based on the principles discussed in the program and their results and interviews with them are included as well as a discussion of the resultant improvements.

Chapter 5 is concerned with the preconceptions students have with electricity. The *Electricity* section of PULP in made up of three sections: electrostatics, capacitors and resistors and electromotive force. *Electricity* is designed as a supplement to the formal lectures given in the Physics programme. It includes worked examples and a series of tutorial-based questions that include formal and operational definitions of the concepts included in electricity. These tutorial questions were assessed immediately and provided students with an indication of their progress in this section. Two tests were given to students, and a discussion of the results is included. Some modifications to the program are also given based on the students' conceptual difficulties as exposed by this research project.

1.2 The use of computers in physics education

Computers, in general, have a profound effect on our daily lives. Technological advances in computer hardware and software have improved our means of travel and communication. The introduction of precision equipment has brought about improvements in the way we are treated for illnesses, for example in the use of magnetic resonance imaging (MRI). The world of finance has become less paper and more spreadsheets and even farming has become a more exact science. These rapid changes to society have created a need for education to be flexible and contemporary (Disessa, 1987).

The use of computers is continually increasing in physics education. Developments in computer technology have resulted in software packages that are used for teaching physics principles and for the collection and analysis of data in real time in the physics laboratory. Theory-based software packages cover a range of topics. Ronen *et al* (1997) have created a program called "DC Kid-Cad" which simulates electric circuits containing various electric components such as bulbs, variable resistors and bells. Electricity poses many problems to students and the main preconception students' hold is that current is used up in the circuit (Duit and von Rhoneck). This program is based on qualitative activities where the student is given an incomplete circuit and under certain conditions is ask to complete it. Further programs dealing with electric field lines and the nature of electric fields produced by point charges are simulated by Holmes' (1990) in a program called "Electric Field Lines Simulation Lab". This interactive program allows students to enter the positions of, up to a maximum of six, point charges and the value for each charge and the computer then calculates the electric field at a chosen field point.

Singer and Ganiel (1990) developed three software programs aimed at enhancing the understanding of geometrical optics amongst high school pupils. The first program deals with the law of reflection, the second with Fermat's principle and the third program deals with thin lenses. Each program is structured into a game and a tutorial that allows the pupil to adjust the various parameters such as thickness and position of the lens. Ruiz (1990) has written programs for first year university students that also illustrate the principles of optics. This program deals with topics such as ray tracing through thin lenses, spherical mirrors and camera lenses. It includes a practice examination that tests the students' understanding. The program allows students to adjust parameters such as object distance, focal length and types of lens and to see how a change in these parameters affects the entire system.

Mechanics is a branch of physics that is concerned with the study of the effect of forces and energy on a system. Hicks and Laue (1989) have used a computer-assisted tutorial in an attempt to dispel the misconceptions first year students have with mechanics. Their tutorial consists of worked examples, discussions on the formal concepts and definitions and multiple-choice questions that are both qualitative and quantitative. Qualitative questions are presented before quantitative as the researchers felt this would encourage the students in the program. Borghi *et al* (1987) measured student success using computer aided teaching tools in the branch of mechanics as well. Their research involved both laboratory experiments and the observation of computer simulations. Students begin by watching simple experiments that introduce the topics of mechanics and then use the computer to simulate those experiments. The program allows for changes to the parameters and this provides the student the opportunity to experiment with physics situations that mimic the actual experiment.

Computers, under the heading of microcomputer-based laboratory (MBL's) tools, have been used extensively in introductory physics laboratories as well. MBL's are probes (measuring devices), which interface with the computer and allow for real time calculations and measurements of physical properties such as sound, temperature and pressure. Trumper and Gelbman (1997) have included an MBL in their investigation into students' understanding of power and work in an AC resistive circuit. The program "Explorer Lab" assimilates data as the experiment is carried out and then displays a graphical representation of it. The purpose is to show students that electrical components cannot be viewed in isolation, and that changes in one part of the circuit affect other components at other parts of the circuit as well. The researchers concluded that students benefited from the simulation by having time, which would otherwise have been spent on the collection of data, to focus on the physical phenomena. As the data was plotted in real time, students immediately observed the affects changes in a part of the circuit had on the entire circuit.

CHAPTER 2
DESIGN STRATEGIES FOR A RESEARCH-BASED INSTRUCTIONAL COMPUTER PROGRAM

2.1 Overview

In order for an instructional software package to make a significant impact on the learning process, the emphasis should neither be placed on its technological ability nor on the achievements of programmers and related programs. In fact

> *"if software developers asked users what they thought was happening in the program and what they were learning, and then listened carefully to the responses, they would take a long step toward developing computer software that would actually promote learning." (Redish, 1993)*

This by no means devalues the role that technological developments and achievements play. However, this must be secondary to the instructional strategies. These strategies include:

- The collaboration of specialists.
- Perceived goals and outcomes.
- Continuous testing and evaluation of students as well as the subsequent modifications to the program.
- A proposed method of integrating the package into the current curriculum.

2.1.1 <u>The instructional software package design group</u>

The design of an effective instructional package poses a huge intellectual challenge. The program must be accurate with regard to the content it delivers. It must be able to adsress the conceptual difficulties experienced by students and finally it must have the strategies for effective learning embedded into its design. The responsibility of completing such an involved and complicated task should not be shouldered by a single person but by a group of specialists. These specialists are the lecturers, computer programmers and researchers into Physics education. This group may be of any size provided there is at least one of each of these specialists listed above present. Meetings between the entire group should be scheduled regularly, as this will prevent any breakdowns in communication. It also allows for the exchange of ideas and proposals for the development and improvement of the program.

Since each member of the group is a specialist, his or her opinion and view on what is relevant and what should be included in the program would differ. A lecturer is a specialist in the content of the course and has experience with the relevant theorems, equations and definitions. The danger in having a design group made up entirely of lecturers is that the program may be seen as a glorified text book, offering content intensive material but not fully utilising the most powerful feature of the computer namely its interactive capability.

> *"Computer-based learning units are not books or films. The instructional developer must learn to use text and graphics in ways that are appropriate for the computer as a learning medium." (Bork, 1986)*

Computer programmers will focus on the technical issues relating to the development of an instructional software package. Their priorities lie in the choice of an appropriate coding language and content presentation. Their choice of coding language must be compatible with any operating system, and must be cost effective and contemporary. Careful investigation of these properties will ensure that the program will execute on all platforms and will have realistic graphics, animation and evaluation capabilities. The use of a contemporary coding language ensures that the program does not become obsolete quickly which would require an upgrade using another coding language. The presentation of the course content should also be judiciously considered. Attention should be paid to:

(a) The legibility of text and graphics. An effective visual cannot even begin to do its job unless all users can see the words.
(b) The sensitivity of the users. The program should not offend, insult or intimidate users. Instructional programs should hold no alliance to political parties, groups or movements, unless designed specifically for that purpose.
(c) The accuracy in the instruction.

Arguably, the most important member of the group is the Physics education researcher, who serves as a link between the lecturer, computer programmer and the student. Having experience with the way students learn and think, and knowledge of the methods used by other researchers to assess student understanding are valuable contributions to the software development group.

2.1.2 Perceived goals and outcomes

Before any software package can be written, prerequisites must be satisfied. The task group must identify its target audience. Knowing the technical experience students have with computers will determine how much time will be spent on using the program or on instructing students on the use of the computer. Knowledge of the education backgrounds of students will help in determining the standard of the class and the true worth of the program. Once the calibre of audience has been determined, the task group must decide on what content area is to be researched. Cognisance of previous research is important as it may identify preconceptions that could have gone unnoticed by the group. The program must be designed to include these findings before the students use it. Furthermore, results from the research group may contribute to the research base. Finally, knowing prior student preconceptions can expedite the design process.

2.1.3 Evaluation and modification of the program

Rigorous testing of the program is *sine qua non*, as this determines the effectiveness of the program. A model of assessment may include interviews with the students before, during and after the interactions with the program. By interviewing the students before they use the program, the group will establish the existing beliefs the students have on the material being taught. Interviewing students whilst they are using the program is enormously beneficial as this provides insight into the way they think. This includes their opinions of the structure and design of the program and also the methods they use to answer questions. By interviewing students on a personal level, a more relaxed atmosphere is created and the instructor is no longer seen as a derivative of a lecturer but as a facilitator of discussion on the difficulties felt by the entire group. A good working relationship will allow more timid students to approach the interviewer and even participate in classroom discussions. The second method of evaluating the effectiveness of the program is by pre-tests and post-tests. The pre-test should be administered before student interaction with the program. This uses the same ideas developed for the use of interviews before the student uses the program. It gives the interviewer an indication of the level of understanding the student has before the use of the program. Post-tests serve as an indication of the effectiveness of the program and of the level of understanding achieved by the student as a result of the program.

2.1.4 Integrating software into the current curriculum

The integration of an effective computer program is seen as a major obstacle. Issues such as venue, time and schedule have to be arranged before students are invited to participate in the program. The integration of computer resources into the curriculum should not be seen as an attempt to replace the lecture. Rather it should be seen as a supplement to the lectures with the lecturer being an integral part to the development and success of the computer program in the curriculum. However, sometimes problems result from the lack of co-operation of lecturers who view computer-aided instruction as a threat to their mode of teaching.

2.2 Discussion of the Authorware programming language which is the basis of Pulp

Authorware is a dynamic authoring environment that was designed for computer-based training. It allows the user quick access to the world of instructional software programming without the tedium of knowing much coding language. Schwamberger and Zainasheff (1997) state:

> *"Authorware is the most powerful and complete authoring environment for creating and publishing interactive information. With it you can create information-oriented applications that are rich in multimedia content and highly interactive"*

The program has many educational features built into its library database. These include templates used for quizzes and in tracking performances of students. It allows for "click and match" interaction media, which are extensively used by kindergarten teachers. As the use of sound effects in the program is possible, teachers use Authorware in their exercises where, for example, children have to relate a musical instrument to a sound by clicking on an on-screen image representing that sound.

The program was also reviewed in the Computers in Physics Education Journal. Justin Watkins (1996), author of this article, wrote:

> *"Authorware offers exceptional handling capabilities of video and sound...(and) is good for interactive multimedia used for presentations of tutorials and tests."*

The use of the Authorware program as a compiler for Physics Undergrauate Learning Program (PULP) was suggested and sanctioned by the Information Technology for Higher Education Division (ITEd) at the University of Natal, Durban. It proved useful in the simulation of the vernier sliders of the vernier calipers and travelling microscope in the *Try These Yourself* sections as well as for the motion of the protractor in the *Minimum Deviation section.* The authoring interface of Authorware centres around the placing of icons on a "flow line" representing the users' route through the package (Figure 2.1).

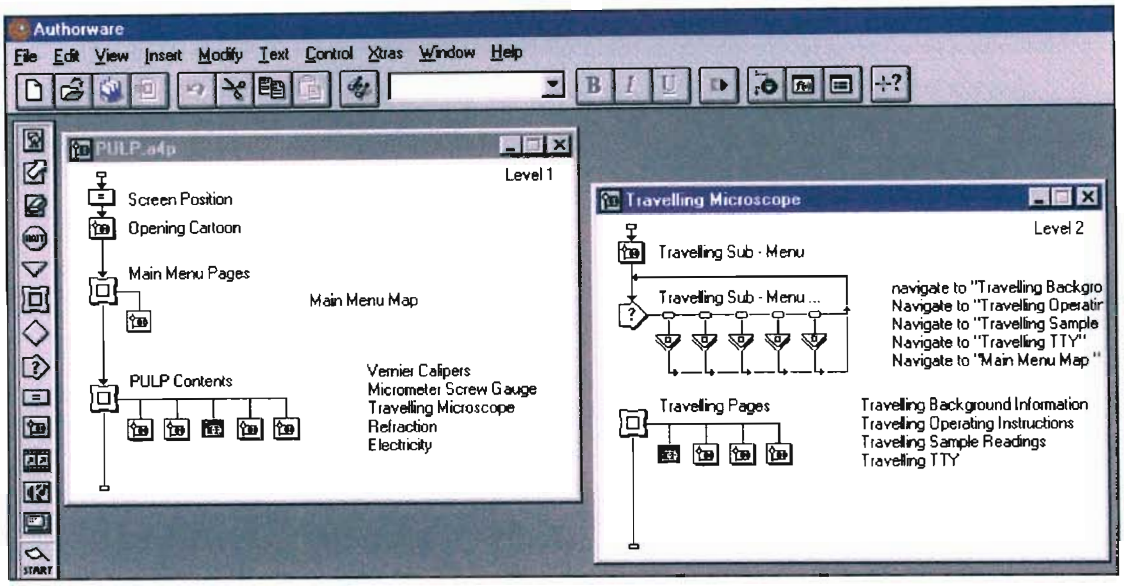


Figure 2.1: Screenshot of the Authorware environment

The screenshot (Figure 2.1) shows the design flow-line of PULP. The blue highlighted box entitled Travelling Microscope, shows the contents of the *Travelling Microscope* section of PULP. The box to the right of this is the main flow that holds the entire contents of PULP. Icons are visual representations of the functions of the program. By dragging an icon from its position on the extreme left of the screenshot activates it. Some icons include motion, pause and picture icons. Others are more advanced, like the framework icon and decision icons that decide where the user goes to next in the program. Authorware allows for the inclusion of calculation code. This is possible with the use of the calculation icon. In the PULP program, the display screen was set to appear in the middle of the screen, irrespective of the monitor size. A smaller display screen size was used, so that the processing speed of the program was not reduced and the program's opening animation sequence ran smoothly.

The ease and functionality of using the Authorware programming language made the designing of PULP possible. A useful introduction to the capabilities of Authorware is the set of tutorial sessions, which provides hands-on instruction on the dynamics of the program.

2.3 Discussion of the volunteer PULP groups

First year introductory students were invited to volunteer for PULP by means of an advertising campaign initiated by the project co-ordinator. Pamphlets and posters were designed highlighting the features of the program and also served as application forms (See Appendix 1 for example of pamphlet). These were distributed to students as they registered for the introductory physics course with the School of Chemical and Physical Sciences. Initially 50 students had applied on registration day, however that number was reduced to 25 students. These 25 students attended the program for its entire six-week duration and made up the test sample. Those students who had not registered for the program were labeled as "NON-PULP" students and their results formed the basis of comparison with the results of PULP students in testing the effectiveness PULP.

Students were labeled "volunteers" as the program was not a mandatory part of the physics course and no additional marks or credits were awarded for attending. Also, as the program was not formally allocated any lecture time, meetings had to be arranged during students' free lecture periods. As a result, the 25 students were divided into four groups. In order to maintain a controlled environment, students allocated to a particular group were not allowed to change groups and, although attendance was voluntary, students were warned that an absence from the program for more than three weeks would result in their expulsion.

Each group had one 45-minute lecture period per week in which to interact with the program. During this time an instructor was present. The role of the instructor was initially to instruct the student on the use of the program. However, as the students become acquainted with the dynamics of the program, the instructor's role shifted to that of interviewer and facilitator. The interviewer's task was to record the reactions of students as they used the program and to determine first-hand what students thought of the program's physical characteristics and of the contents being delivered. This information was used to improve the program by changing the text, graphics and the resolution of the images as well as the interactive capabilites. More importantly, these interviews gave valuable insight into the preconceptions that students held with the topics contained in PULP. Identifying these preconceptions lead to the program being modified in order to bring about conceptual change.

Both groups were subject to written tests on topics covered in the program. Tests were administered one week apart at a common venue. Questions for these tests were adapted from past examination and test questions. The results of each group were compared, as an indication of the effectiveness of the program. Interviews were conducted with the students, and questions were based on their replies in the tests. The responses to these tests further highlighted the difficulties students had in their understanding of physics. The difficulties lead to further modifications of the program.

In order to validate that the sample used for the program was a general representation of the student population enrolled for the introductory physics course, a survey of both groups of students (PULP and NON-PULP) was conducted. This survey was based on whether the student had taken mathematics and/or physics at high school level, at what grade these subjects were written (either higher or standard grade) and the symbols obtained for each subject. The results of the survey are shown in Table S1 and Table S2.

		HIGHER GRADE						STANDARD GRADE					
		A	B	C	D	E	F	A	B	C	D	E	F
MATHEMATICS	PULP STUDENTS (N = 16)	1	1	2	3	3	0	0	0	3	1	1	1
	NON – PULP STUDENTS (N = 139)	4	12	16	24	24	4	9	13	14	8	7	4

Table S1: Results of performances of both groups in mathematics at high school level

Of the 139 NON-PULP students surveyed, 84 had written mathematics at the higher-grade level and 55 had written at the standard grade level. Four of these students had obtained "A" symbols (>79%) at higher grade level and nine had obtained "A" symbols at standard grade level. The average percentage of the entire sample of higher-grade NON-PULP students in mathematics is a lower "D" symbol (between 50 and 55%). The average percentage of the entire sample of standard grade NON-PULP students in mathematics is a higher "D" symbol (between 55 and 65%)

Of the 16 PULP students surveyed, 10 had attempted Mathematics at higher-grade level and 6 at the standard grade level. One student had obtained an "A" symbol at higher-grade level. The average percentage for higher-grade students is a higher "D" symbol, whilst the average percentage for the standard grade was a "D" symbol (50%).

		HIGHER GRADE						STANDARD GRADE					
		A	B	C	D	E	F	A	B	C	D	E	F
PHYSICS	PULP STUDENTS (N = 12)	2	0	3	5	0	0	0	0	0	1	0	1
	NON – PULP STUDENTS (N = 117)	7	17	26	23	18	2	1	6	5	4	8	0

Table S2: Results of performances of both groups in physics at high school level

Of the 117 NON-PULP students surveyed, 93 had attempted physics at the higher grade level and 24 at standard grade. Seven students at higher grade and one at standard grade had obtained an "A" symbol. The average percentage for both higher and standard grade is a higher "D" symbol.

Twelve PULP students were surveyed. It was found that ten had written physics on the higher grade and 2 on the standard grade Two students had obtained distinctions for higher-grade physics and the average percentage for both grades is a higher "D" symbol and an "E" symbol respectively.

It should be noted that three students enrolled for PULP did not attempt physics at high school. One student was repeating the course. A large percentage (78%) of PULP students were successful candidates of the bridging course at the University (Science Foundation Programme).

CHAPTER 3
INVESTIGATION OF STUDENTS' UNDERSTANDING OF THE USE OF BASIC MEASURING INSTRUMENTS

3.1 Introduction

Physics is said to be an empirical science which leads to theoretical conclusions (Feynman, 1964). As such, many physicists believe that a true measure of students' understanding of physics concepts can be made in the laboratory (Duggan *et al*, 1996). The laboratory environment serves as a reinforcement of the theory discussed in formal lectures and provides students with "hands-on" experience with these principles. The American Association of Physics Teachers (2002) has developed a set of goals aimed at developing effective introductory physics laboratories. Highlighted in these goals is the importance for students to gain experience in the use of laboratory equipment including measuring instruments.

> *"...it is imperative that students have a broad experience with techniques using laboratory equipment...it is advisable that students use many different types of basic laboratory apparatus to make observations."*

However, often laboratory sessions are viewed as a set of tasks that must be completed, where emphasis is placed on the final answer rather than the concept being tested (van den Berg, 1992).

There has been a great deal of discussion about the uncertainty students have in experimental measurements (Kirkup *et al*, 1998; Albers *et al*, 2002; Allie *et al* 2002). Buffler *et al* (2002) investigated the methods used by students when recording measurements in a laboratory practical. They modeled their analysis according to the point and set paradigms. The point paradigm suggests that every measurement taken is correct without any uncertainty whilst the set paradigm assumes that every measurement is an approximation of the true value. Their research showed that many students repeated measurements until they found a recurring value (which they then took as the correct reading), rather than repeating the measurements and then taking the mean of those measurements as the approximate reading.

Campbell *et al* (2000) investigated students' ability to give written reports on the laboratory experiments that they had done. The research found that the method used in the actual experiment was different from what students wrote about in their reports. The relevance of what should be included in their reports was influenced by the students' awareness of what outcomes were expected by the practical and the underlying theory being tested. The procedures necessary and the precautions taken in the practical also served as factors influencing their reports. Finally, the understanding students had about the theory involved before the practical counted towards the conciseness of the write-up. They concluded that many students' under-report their experimental procedures due to a lack of experience and understanding of the factors listed above.

3.2 Description of the design structure of *Basic Measuring Instruments*

Although research has centered around the introductory physics laboratory in general, little research has been carried out to investigate the difficulties students have with basic measuring instruments. Many students attempting physics at first-year level have not used these instruments at school. Their prior experience was in the use of rulers to record linear dimensions and these were taken either in millimeters or centimeters. The use of measuring instruments, which include the vernier calipers, torsion balance, micrometer screw gauge and travelling microscope, is introduced during the first six months of the year in the physics program at the University of Natal, Pietermaritzburg, and these instruments are used in various experiments throughout the year. A typical laboratory session has approximately thirty pairs of students and two demonstrators tasked with assisting them in the use of these instruments. During the laboratory session students are presented with a video demonstrating how each instrument is to be used, and their introduction is supplemented with a set of course notes. The high student to demonstrator ratio makes learning the use of these instruments tedious and time consuming. As a result, many students seek only the final measurements to complete the set tasks without any consideration of acquiring any understanding and sometimes demonstrators conduct the entire experiment on their behalf.

In an attempt to improve student understanding and to compensate for the lack of person power, PULP includes a simulation of some of the instruments used in the introductory physics laboratory. The *Basic Measuring Instruments* section of PULP comprises the V*ernier Calipers*, *Micrometer Screw Gauge* and the *Travelling Microscope* subsections offering instruction on instruments of the same names. The simulator contains actual images of the instruments and maintains a sense of reality by simulating the movements of the vernier calipers and travelling microscope (also known as the vernier microscope).

As the design structure for each instrument in the *Basic Measuring Instruments* section of the program is the same, a general discussion for all instruments is given. Each instrument is made up of many components that have their own particular function and use. Some particularities exist, for example, the fine adjustment screw that allows for small movements of the travelling microscope can not be operated if the course adjustment is not fully tightened. Knowing the names of these components and their purposes helps determine whether a student makes an accurate measurement or not. To acquaint students with these functions, a brief explanation is given in *Background Information* (Figure 3.1). These explanations include an actual on-screen image to show the student the location of the components on the instrument itself.

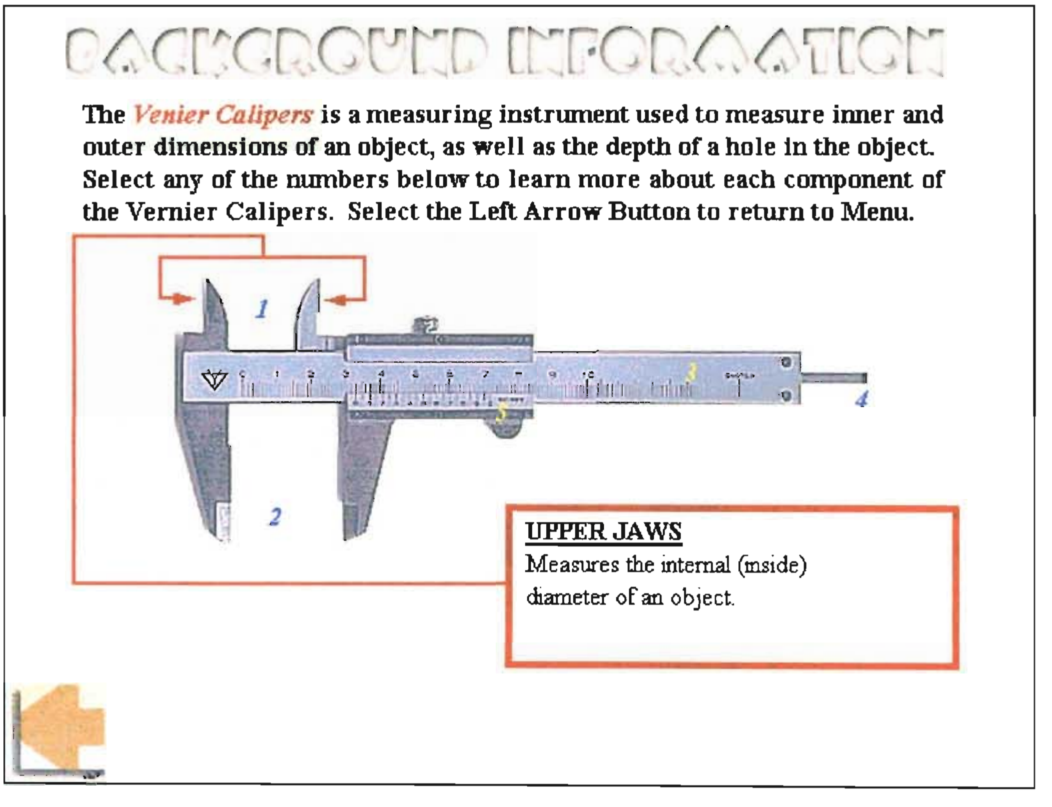


Figure 3.1: Display window of Background Information with reference arrows shown

There are two sub-sections that describe a method for taking measurements from an instrument. This method was developed in conjunction with lecturers concerned with first year experiments and with students who have had previous experience and success with these instruments. The first sub-section *Operating Instructions* (Figure 3.2) gives a detailed explanation in a numbered step format. In order to display each explanation, the student may select any of the numbered buttons. However, since each number on the button indicates the sequence of obtaining a measurement, students are encouraged to follow the ordering of the numbers on their first attempt.

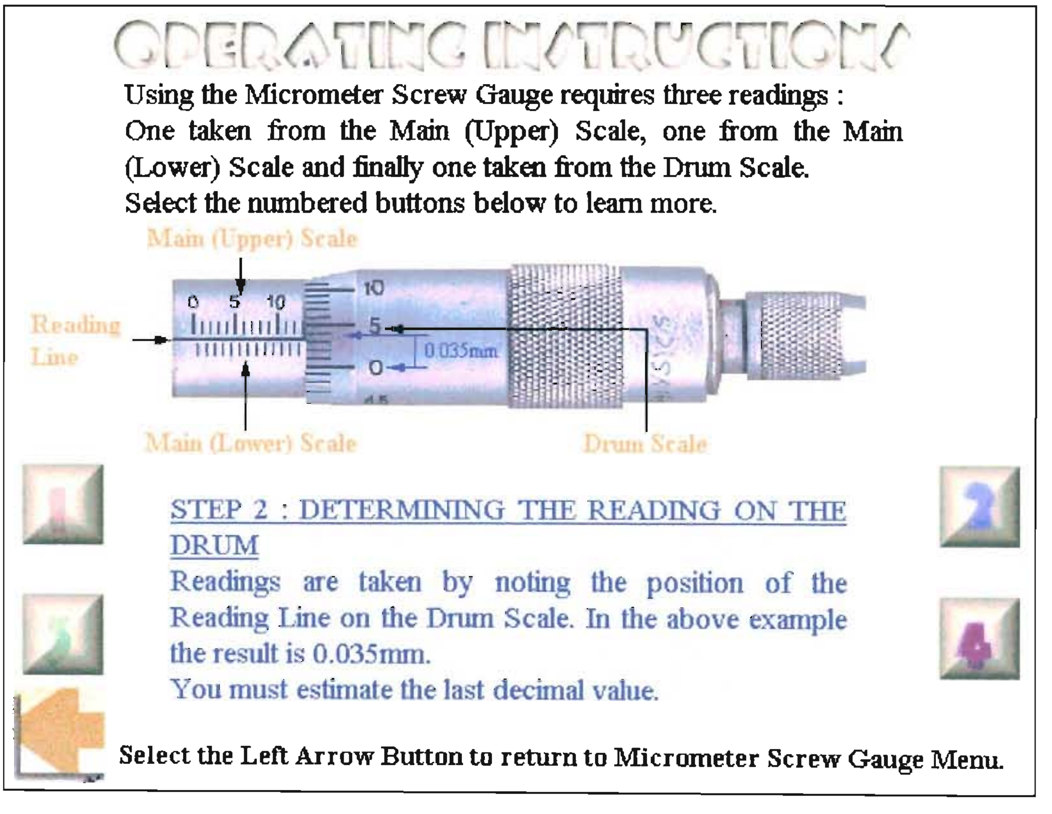


Figure 3.2: Display window showing how to take measurements

Each numbered button has an explanation that is accompanied with a reference arrow showing the reading on the instrument itself. These reference arrows allow students to verify that the reading presented in the text matches the reading on the instrument. *Sample Readings* (Figure 3.3) is less descriptive in its attempt to explain how to take measurements by only presenting final answers. However, if the student is still unsure and requires some reinforcement, a reference arrow appears by passing the cursor over each step. Some illustrations include measurements that involve a reading from the main (lower) scale. This is to show students how the reading of this scale affects the reading taken from the drum scale by increasing the reading by 0.5mm.

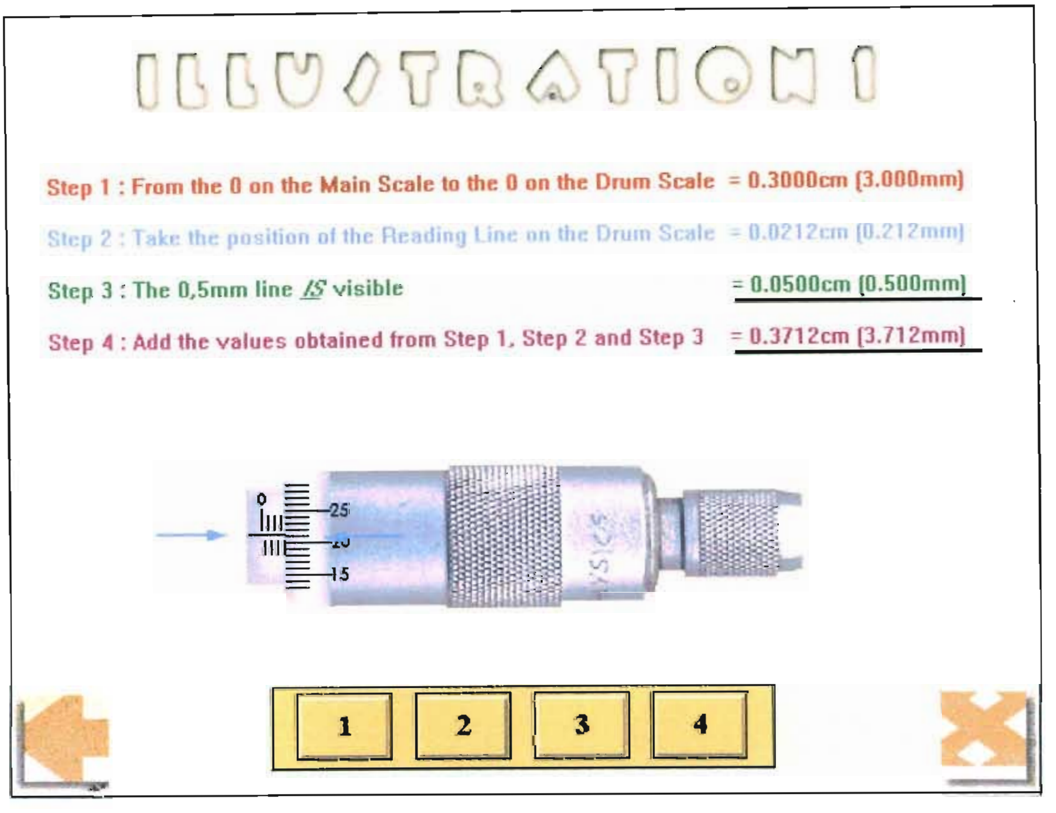


Figure 3.3: Sample reading showing a reference arrow for Step 2

Finally, students apply what they have been taught in the *Try These Yourself* section. In the case of the *Vernier Calipers* and *Travelling Microscope* section of the program each object box is randomly generated (Figure 3.4). The maximum and minimum length of this object box is determined by a random number generator function that is embedded into the programming logic. The student slides the vernier scale slider from left to right until the crosshairs are directly aligned with the right edge of the object box. The crosshairs move simultaneously and in the same direction as the vernier scale slider. Once the crosshairs are aligned, the student enters the measurement into the text entry box. The computer evaluates each student entry and responds with an "Incorrect" or "Correct" display. Thereafter, the next image is generated.

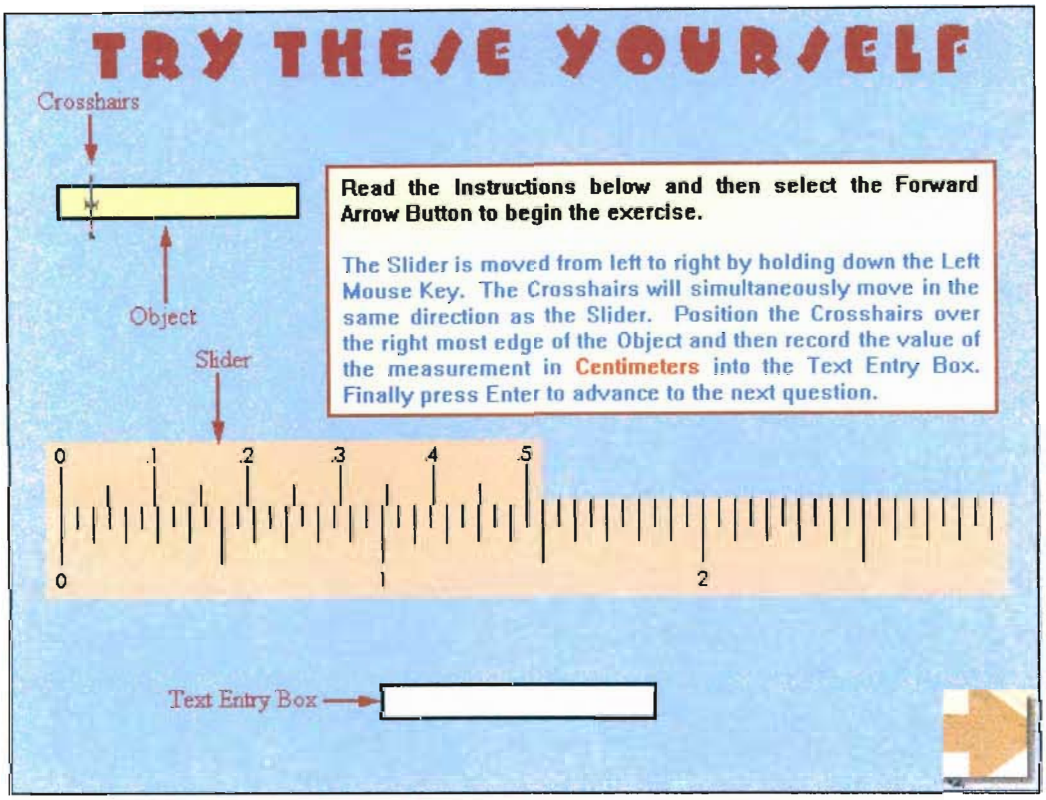


Figure 3.4: Try These Yourself for Travelling Microscope

The *Try These Yourself* section of the *Micrometer Screw Gauge* does not have the animation and level of interaction as the *Try These Yourself* sections based on the other two instruments. Rather it consists of a database of scanned images of the micrometer screw gauge. This database contains eighteen images showing the drum, main and lower scale of the instrument (Figure 3.5). Students are tasked with reading the measurements of these scales and entering the value into the text entry box. In order to maintain a degree of realism between the instrument they see on the screen and that which they use in the laboratory, some images show the position of the zero division on the drum scale below the reading line. Some images show measurements where the division on the lower scale must be included. Readings also include measurements where students have to approximate the last significant figure. They are required to take very small readings as well. The students are required to read the measurements of these scales and enter the value into the text entry box. Once again, the computer evaluates the answer and displays either a "Correct" or Incorrect" response. The next image is then displayed.

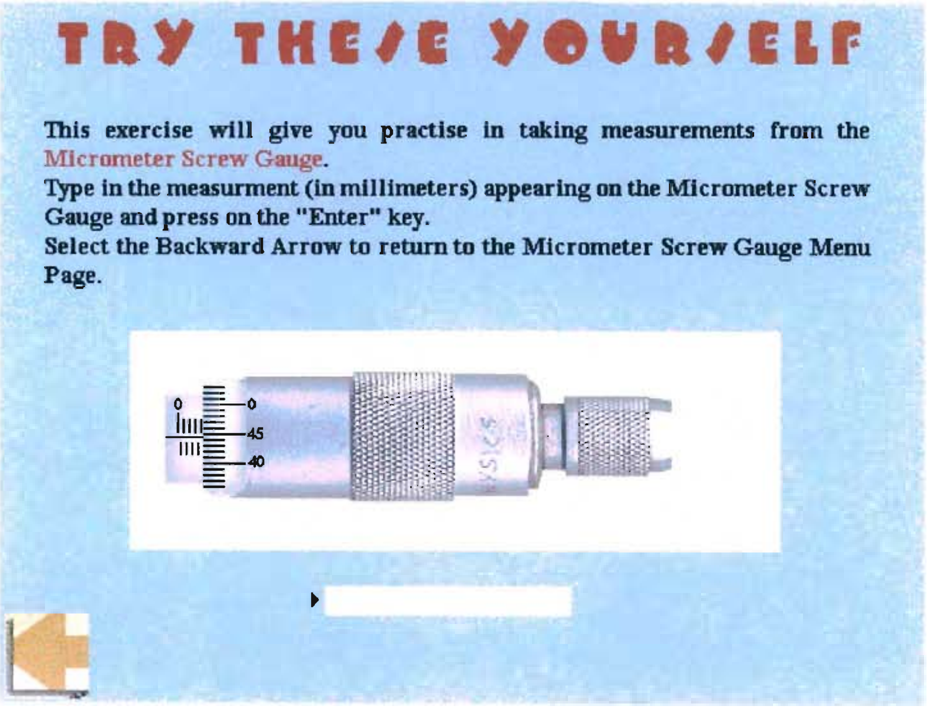


Figure 3.5: Randomly selected image for self test of Micrometer Screw Gauge

3.3 Assessment of students' interaction with *Basic Measuring Instruments*

Both assessments were in the form of written tests administered one week apart, and consisted of images of the three measuring instruments (Appendix 2 and 3). Each assessment was fifteen minutes long. Students were required to record each of the measurements and points were allocated for the correct number significant figures and correct units. After the first assessment, students were interviewed and some practical difficulties were identified. The program was subsequently modified to include these difficulties and the general comments made by students. A discussion of the modifications to the program is given later in this chapter.

Between the first and second assessment, students had two forty-five minute periods to interact with the program in the presence of an instructor. The first interaction was directly after the first assessment and the second interaction was directly before the second assessment. The first assessment was used to give an indication of the students' understanding of basic measuring instruments before they used the program. By having an assessment directly after the two PULP sessions gave an indication of the effectiveness of the program. The second interaction involved using the modified program. Results for both assessments are summarised in Table I1.

		Correct Answer (%)	Significant Figures (%)	Units (%)	Success Rate (%)
V.C	First Assessment	75	54	59	62
	Second Assessment	78	72	66	72
M.S.G	First Assessment	42	42	36	40
	Second Assessment	57	48	50	52
T.M	First Assessment	51	46	42	57
	Second Assessment	61	56	43	62

Table II: Summary of student performance for both assessments on BMI.

3.3.1 Interviews with students after assessment

Interviews were conducted with the entire PULP volunteer group, which consisted of twenty-five students. From these interviews, some of the difficulties students have in recording measurements using the instruments were identified. The interview began with a general question to determine which of the instruments the student had the most difficulty with. Despite most students having difficulties with the travelling microscope (48%), with 33% finding difficulty with the micrometer screw gauge and 19% with the vernier calipers, there was a commonality in the difficulties students have with taking measurements. Some of the responses for each of the measuring instruments are quoted below and are given as illustration of this. It should be noted that these responses are quoted verbatim and that for many students English is not their first (sometimes second or third) language.

(1) Student responses concerning the difficulty they experience using the Vernier Calipers

> *"Personally the measuring device I don't know to how many decimal place it measures. Usually this device gives me problem, I usually get the main scale reading but the vernier scale is hard and to how many decimal places it measures."*

> *"I couldn't understand which one (referring to the scales of the vernier caliper) is read in centimeters and millimeters. Also which one is read in meters. Taking a reading to correct decimal places and significant figures."*

(2) Student responses concerning the difficulty they experience using the Micrometer Screw Gauge

> *"I couldn't differentiate between what is read in centimeters and millimeters and lastly getting the zero reading."*

> *"With this instrument I think that I'm fine but the problem is how to many decimal places it measures to."*

(3) Student responses concerning the difficulty they experience using the Travelling Microscope

> *"The problem I experienced the most were with the travelling microscope. Firstly I found the whole handling of the of the*

apparatus cumbersome and secondly I found that I battled to read the scales accurately."

"I don't know where to start like the initial reading and the final reading and taking a reading to correct significant figure and decimals."

The interview then asked specific questions relating to which question the student had answered incorrectly. A sample of such an interview, conducted by the instructor (I) of the program is given below for a student (S) who answered the question on the travelling microscope incorrectly.

I: Many students find taking the measurements from the travelling microscope most difficult.

S: Yes me too that's why I got it wrong.

I: What method did you use to answer this question? What were you thinking?

S: Well I started from here (student indicates the edge of the vernier scale slider).

I: Why did you start from there and not from the zero of the vernier scale?

S: Because that's where the measurement starts from. Doesn't it?

I: I don't know. You tell me.

S: Well it starts there and then I took the value from the main scale and added it to the value of the vernier scale.

I: What's the value for both these scales?

S: Well for here (indicates the main scale slider) the answer is 77.

I: 77 what? What is the unit for the measurement?

S: 77 millimeters.

I: OK, what is the rest of the reading?

S: Then the reading here (indicating the vernier scale slider) is 0.045mm and then since the 0.5mm mark is showing the final answer is 77.545mm.

I: But you're taking the measurement from the zero on the vernier scale and why are you adding 0.5mm to your final answer?

S:Because...er...I just don't know!

Interviews with other students showed that many were unsure of what role the main (lower) scale on the travelling microscope played.

From interviews conducted with all the students, the following most common difficulties were identified in their use of the instruments:

(1) How many significant figures are required for each of the measurements?
(2) Students were unsure of the value of each division on the scales of the instruments. Does it represent 1 or 0.1 or 0.01 and what are the units for each instrument?
(3) Up to which point should one take a measurement i.e. the edge of the vernier scale slider or the zero on the vernier scale slider?

A common comment from students was that the program allowed them only one attempt at each question before the next image was generated. Also that a mere incorrect reply from the computer was seen as being harsh and very uninformative. Many wanted more attempts at each question with a hint given for each wrong answered entered.

3.3.2 Modifications to the program

To counter the taking of the reading from the edge rather than the zero on the vernier scale slider the program was modified to include an arrow such as the one shown in Figure 3.6. This was included into the *Operating Instructions* display page. For each sample reading page, a cautionary note was given instructing students that the zero on the vernier scale slider and not the edge was to be considered in the measurement. Each hint in the *Try These Yourself* section also displayed a similar caution.

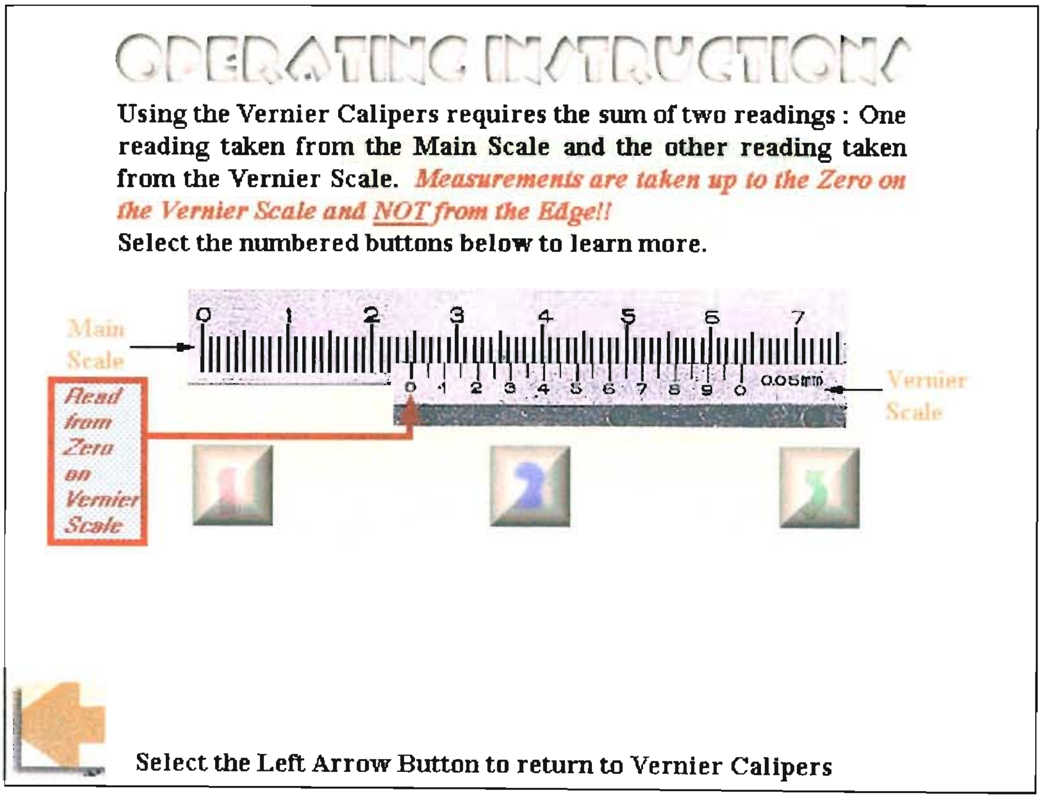


Figure 3.6: Improved display page highlighting that the reading should be taken from the zero on the vernier scale slider

An additional set of instructions (Figure 3.7) in a scrolling text format was included into every self-test page. It was hoped that even if the student overlooked the formal instruction page, then by having a set of instructions on display in the self-test page itself will allow them to use the simulation effectively. The instructor reported that all students agreed that the inclusion of this set of instructions made using the program easier and some said it improved their understanding of basic measuring instruments.

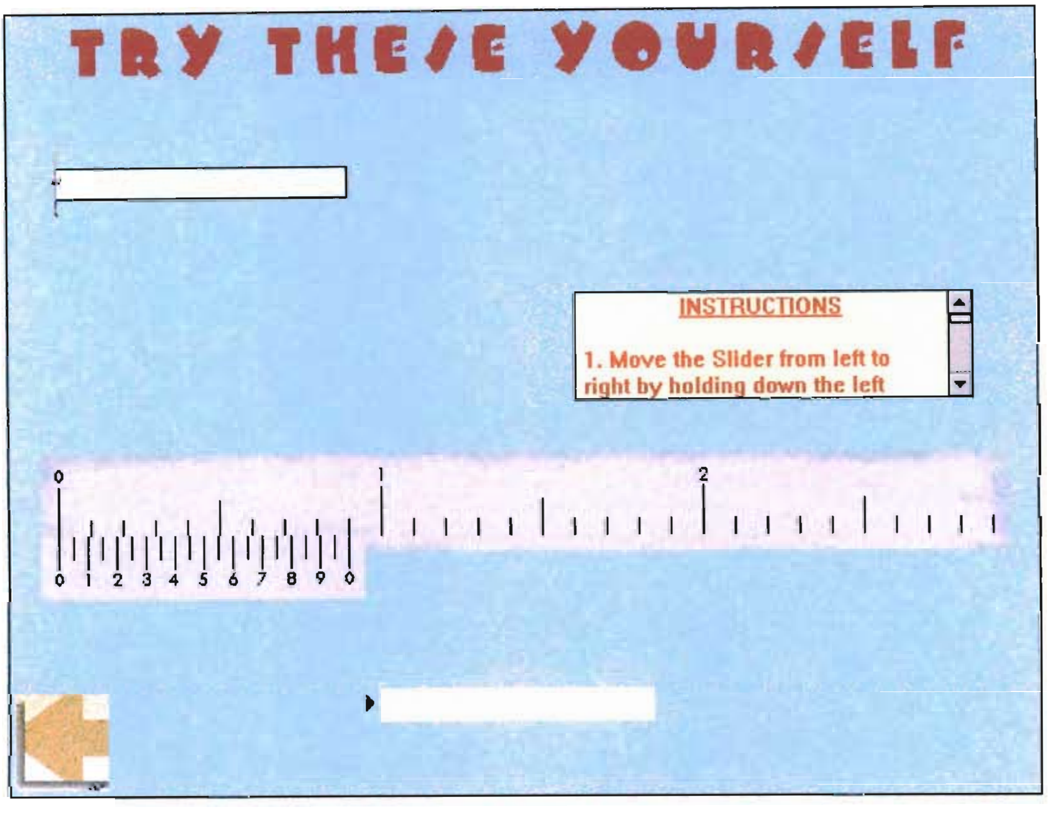


Figure 3.7: Instructions for the vernier calipers embedded into the self-test section

It was decided to address the problems of the number of significant figures, the value of each division on each scale and the starting and ending points of the measurements all at once. This was achieved by introducing three attempts at each question and by providing hints for each incorrect attempt (Figure 3.8). The alternative method used proved to be successful as the results for each instrument shows (Graphs 3.1 to 3.3).

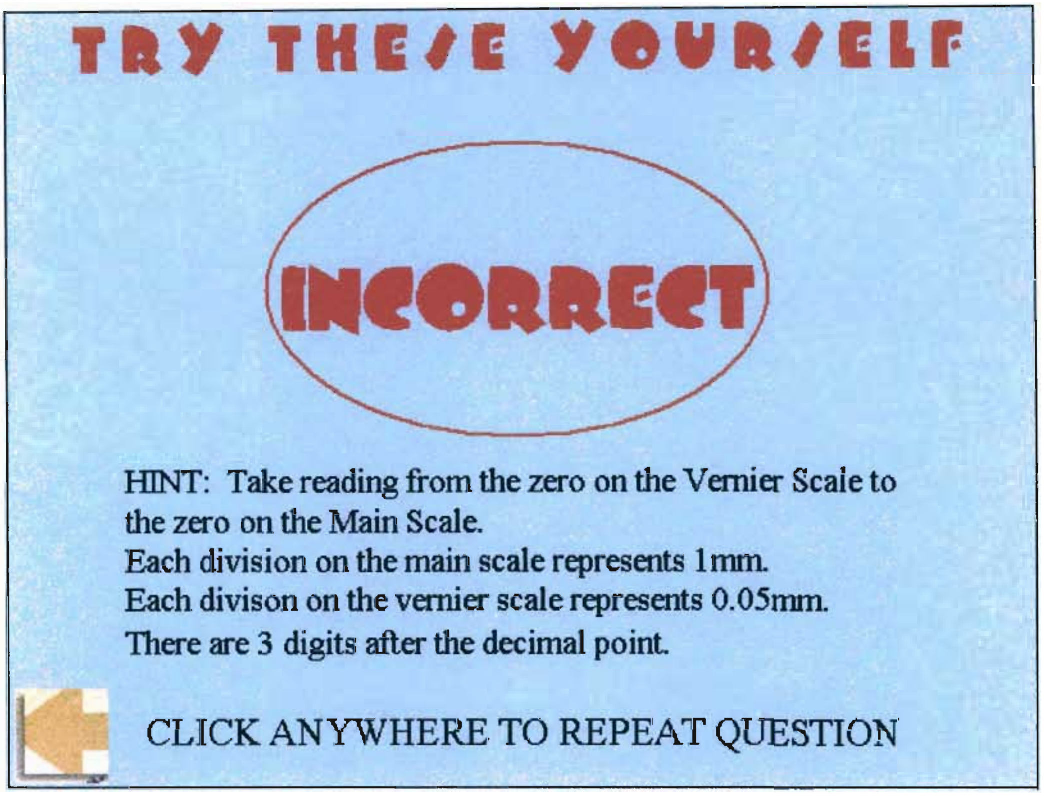


Figure 3.8: Improved response showing hints given for Vernier Calipers

3.4 Summary of *Basic Measuring Instruments*

This section of the program was generally well received by students as it served as a refresher course on the use of the measuring instruments.

> *"...PULP has made physics pracs more bearable, cos' there's more practice and we become more confident and understand better when doing the sample and examples."*

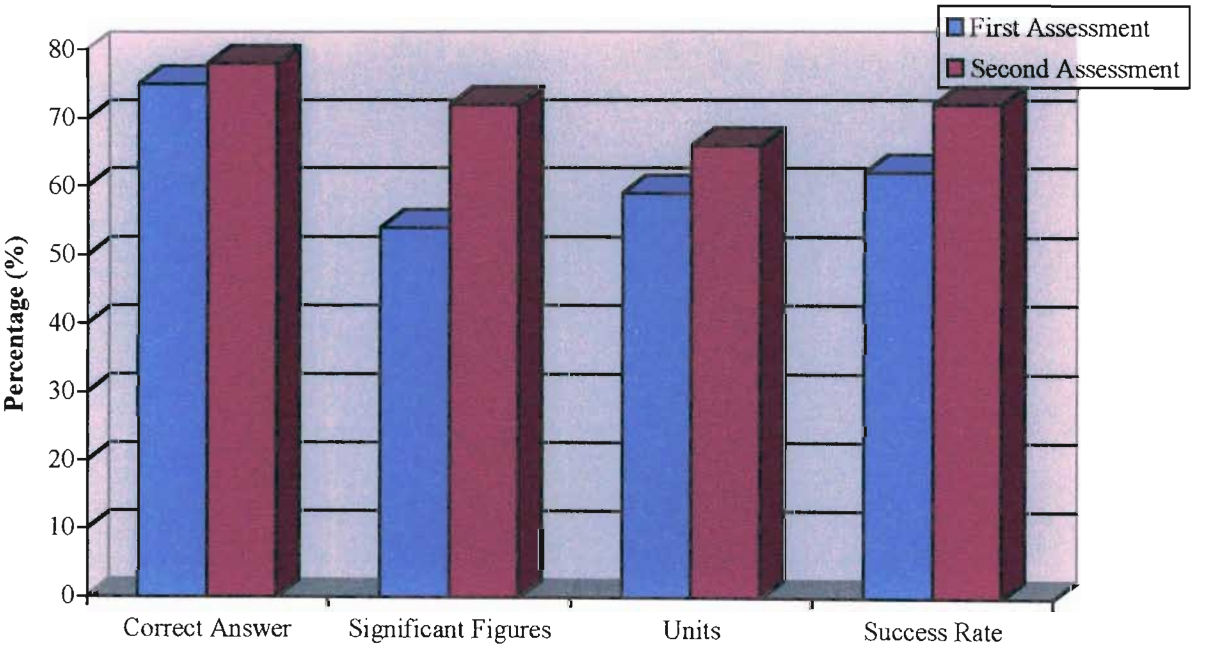
Investigations have revealed that the practical tends to focus on the completion of tasks rather than on the understanding of the instruments.

> *"In pracs we had they (demonstrators of physics experiments) assumed that we had practical experience in handling the equipment. The time allocated was too little and the tasks at hand required much more time. The program (PULP) has a detailed and interesting way of showing us the use of the relevant instruments."*

Many students concentrate on completing these tasks which they view as an indication of success in the use of these instruments. However informal conversations with students and results from PULP show that when called upon to use these instruments in later experiments, many students have difficulty in reading the measured value from the instruments. By emphasizing the fundamentals of each instrument, such as the value of each division, the points that the reading must be taken from and the general use of the instruments, PULP has shown an improvement in the students understanding.

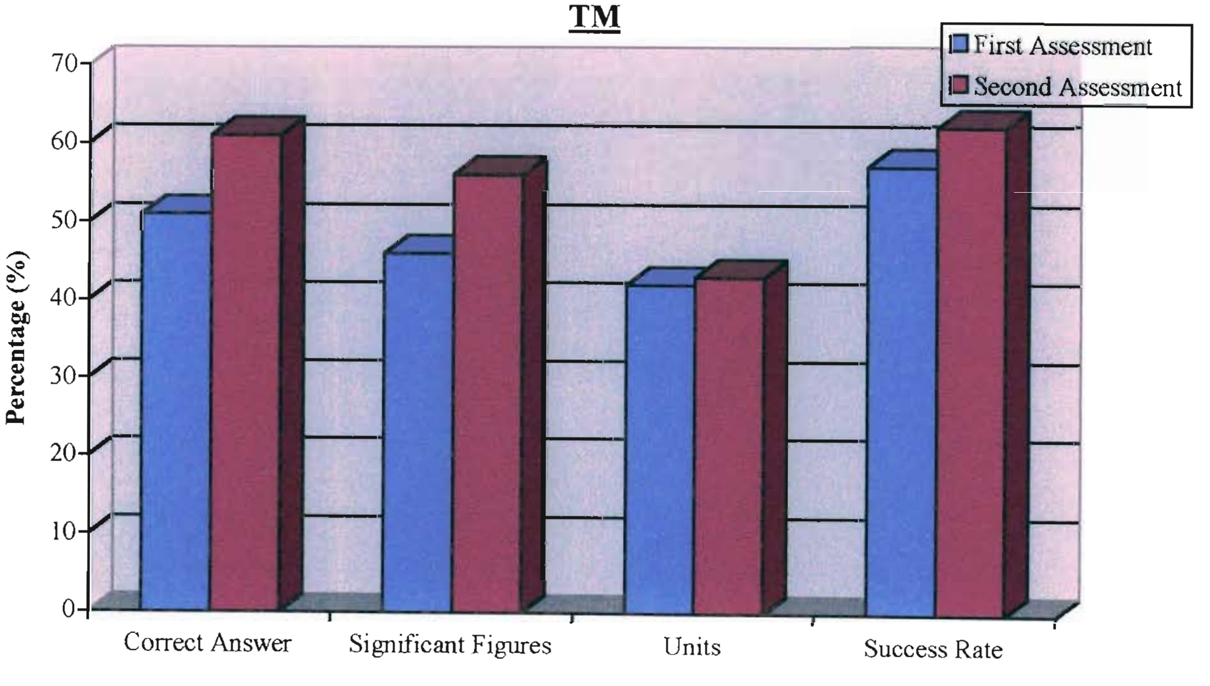
An analysis of the assessment of *Vernier Calipers (VC)* (Graph 3.1) shows that all PULP volunteers registered improvement in their results. A significant improvement, from 54% to 72%, was recorded for significant figures. This was particularly encouraging as most students said that significant figures were one of the difficulties they had with the instrument.

Graph 3.1: Summary of student perfomance on both assessments for VC



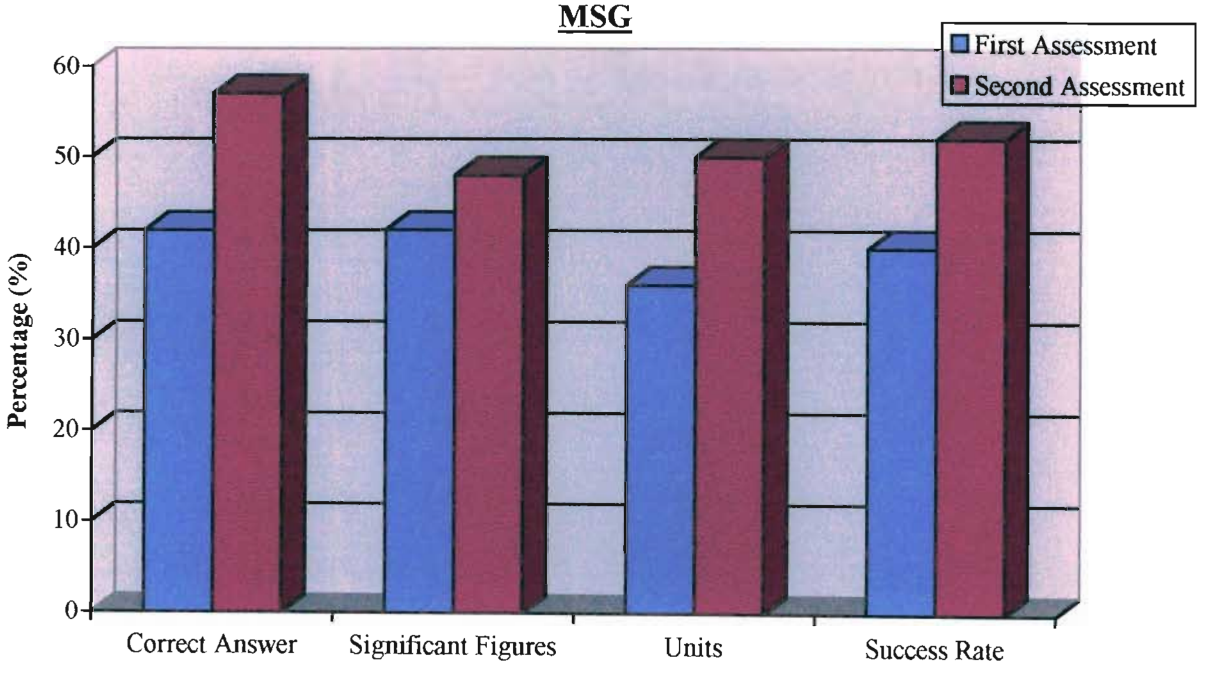
The primary difficulty experienced by students using the travelling microscope was from which points they should take the measurements, either the edge of the vernier scale slider or from the zero. The program was modified to include clear indications of the correct point from which to take the readings and this is reflected in the results (Graph 3.2). An improvement of 10% was recorded for correct answers and lesser gains have also been recorded for significant figures, units and success rates.

Graph 3.2: Summary of student perfomance on both assessments for TM



Measurements taken from the micrometer screw gauge are especially difficult as students have to be aware of the readings from three scales, the drum, main and lower scales. The inclusion of a reading from the lower scale results in an increase of 0.5mm in the entire measurement and the zero division on the drum scale may appear above or below the reading line. An analysis of the assessment of *Micrometer Screw Gauge* shows that students have improved in all areas relevant to taking a measurement from this instrument (Graph 3.3).

Graph 3.3: Summary of student perfomance on both assessments for MSG



CHAPTER 4
PULP ASSESSMENT OF THE SIMULATION OF REFRACTION OF LIGHT THROUGH A TRIANGULAR PRISM

4.1 Introduction

The study of optics, both physical and geometric, is introduced to students at high school with topics such as reflection, interference and the photo-electric effect. These topics are continued at university level with the addition of, amongst others, refraction of light, Snell's Law and thin lenses. Research in physics education shows that students' understanding of fundamental optics concepts remain low, and most students have difficulty regarding the physical behavior of optical systems (Salinas & Sandoval, 2001). Furthermore, their preconceptions of the principles governing the behavior of light are often at variance with physics ideas developed in formal lectures and laboratories (Goldberg & Bendall, 1995). These preconceptions are developed from their early life experiences and are resilient to change (Watts, 1985).

The thin lens formula is used in introductory physics courses and in the laboratories to calculate the focal length of a thin lens by determining the distances of the image and object. Chakravarti and Siegel (2001) have rewritten the thin lens equation into a straight-line equation. They argue that

> *"Graphing the data gives students a visual verification of the thins lens equation, as well as practice in graphical analysis" and "although a straight-line graph ...does not verify any fundamental law of physics ...we found that students enjoy the experiment even more when the image and object data is graphed."*

Investigations have also been conducted on students' understanding of images formed by lenses and mirrors. Goldberg and McDermott (1987) found that students were able to give correct verbal explanations of the conditions necessary for the formation of real images. Students also displayed sound knowledge of how the properties of lenses, mirrors and screens affected this formation. The researchers found, though, that the same students were not able to relate their theory to the practical environment and few were able to replicate the result of their theory prediction.

Singer and Ganiel (1990) conducted further independent research into students' ability to relate theory to practical situations using plane mirrors. The image formed by a plane mirror is as far behind the mirror as the object is in front of it. Students however have difficulty conceptualising the symmetry that exists between the image and the object and as such hold the preconception that the image is actually formed on the plane of the mirror.

Guesne (1985) investigated the preconceptions held by children aged between 10 and 14 years old, with regard to the properties of light. The findings show that children hold the belief that the eye is not the recipient of light from objects but the propagator. Further findings showed that the use of common phrases in childrens' conversation with each other, such as staring daggers, implied that objects were being "looked" upon by the eye and not receiving light from them.

4.2 Description of the design structure of *Minimum Deviation*

Snell's Law states that for light travelling from one medium into another medium, the product of the refractive index and angle of incidence in one medium is equal to the product of the refractive index and angle of refraction in the second successive medium. This law is defined algebraically by $\boldsymbol{n_1 \sin\theta_1 = n_2 \sin\theta_2}$, where $\boldsymbol{n_1}$ and $\boldsymbol{n_2}$ are the refractive index of the first and second mediums respectively. θ_1 and θ_2 are the angles of incidence and refraction respectively.

An application of Snell's Law is seen in the path traveled by light as it passes through a triangular prism. Consider (Figure 4.1) a ray incident, at the angle θ_1 on a face of a prism of refracting angle A and refractive index n. Since the exterior angles of a triangular prism is equal to the sum of the interior opposite angles it follows that

$$\delta = \theta_1 - \theta_1' + \theta_2 - \theta_2'$$

Further, since the sum of the angles q1' and q2' is supplementary to the angle B and the latter is the supplement of the angle A, we have the additional realation

$$A = \theta_1' + \theta_2'$$

Hence applying Snell's Law at the two refractive surfaces

$$\sin\theta_1 = n\sin\theta_1'$$
$$\sin\theta_2 = n\sin\theta_2'$$

and eliminating the angles of q1' and q2' from among the above four relations we obtain finally

$$\delta = \theta_1 - A + \sin^{-1}\left[\left(n^2 - \sin^2\theta_1\right)^{1/2}\sin A - \cos A\sin\theta_1\right]$$

An analysis of this formula shows that for any given prism there is a value for the angle of incidence θ_1 for which this deviation angle δ is a minimum.

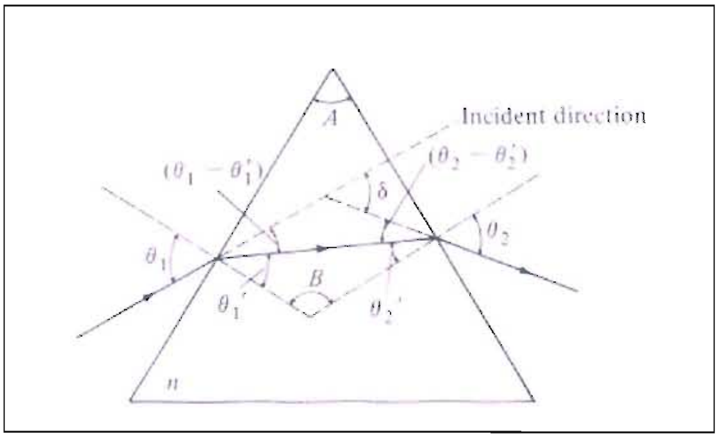


Figure 4.1: Path of light through a triangular prism

The concept of minimum deviation of light passing through a triangular prism is introduced at first year level in formal lectures and in the laboratory. During laboratory sessions, students determine the minimum deviation of laser light passing through a triangular perspex prism. The experiment is very cumbersome and practically difficult because the students are meant to rotate the prism (or laser light source) whilst searching for the minimum deviation condition. The degree of impreciseness is often significant.

The *Minimum Deviation* section of PULP simulates the refraction of light through a triangular prism. Each ray (incident, emergent and refracted) is clearly labeled and explained (Figure 4.2) in *Background Information.* A discussion of the minimum deviation of light passing through a triangular prism is given, illustrating the concept of symmetry, which includes the mathematical consequence of symmetry (i.e. $\theta_1 = \theta_4$ *and* $\theta_3 = \theta_2$).

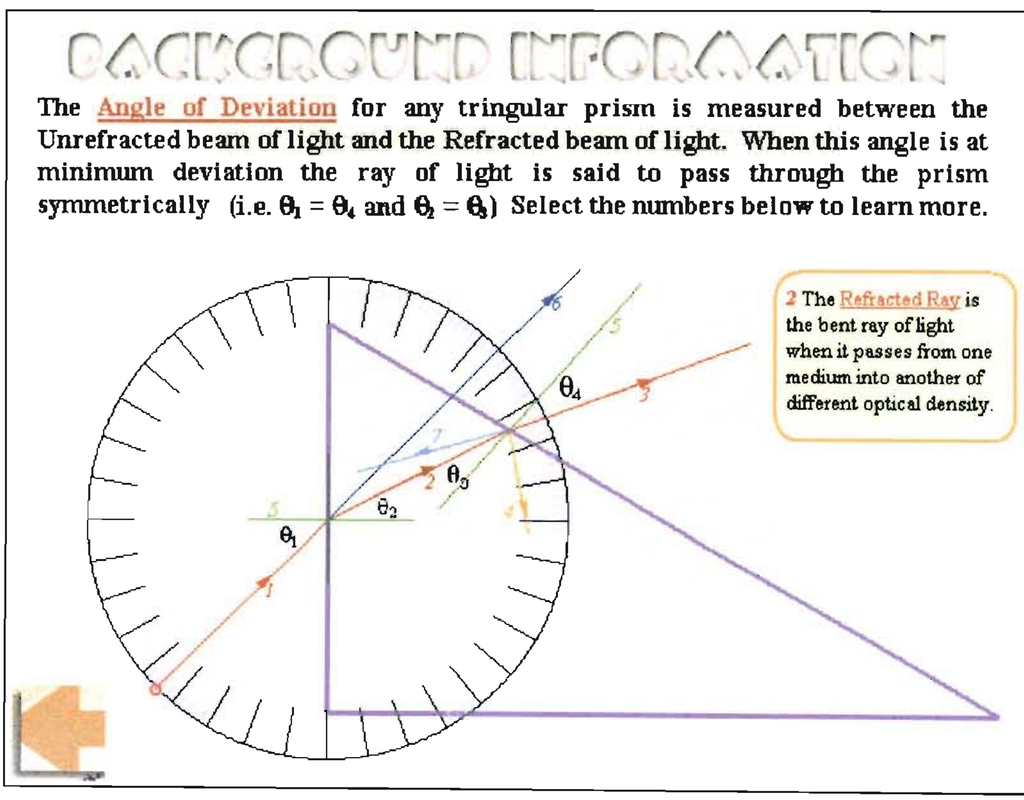


Figure 4.2: Background Information window showing definition of rays

Examples of light entering the triangular prism at various angles are given in the *Worked Examples* section, illustrating how the angle of incidence, refraction and emergence is formed and measured (Figure 4.3). Placing the mouse over any of the angles represented in the diagram results in an explanation of the measurement and how the angle is formed. This visual and textual representation draws the students attention to the name and location of the angle as well as how to calculate it.

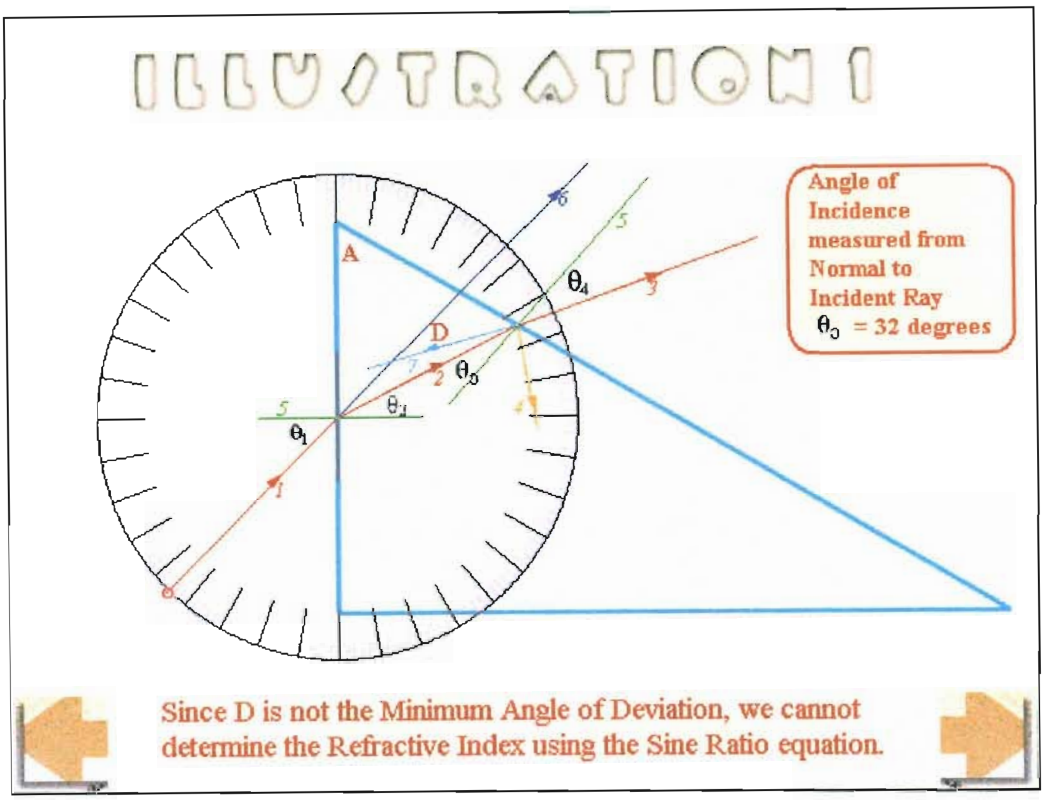


Figure 4.3: Sample reading defining the various angles of light

A degree of realism is included in the *Try These Yourself* section (Figure 4.4). The student is presented with three prisms made up of everyday materials such as glass, water and perspex. The aim here is to determine the refractive index of the prism by moving a light source in a limited arc around the prism of their choice. Once the student has decided on a position for the light source, they select the draw button to display the passage of light through the prism. Additional lines include the normals at both interfaces, the reflected ray and the undeviated rays (ray 6 and 7 in Figure 4.3).

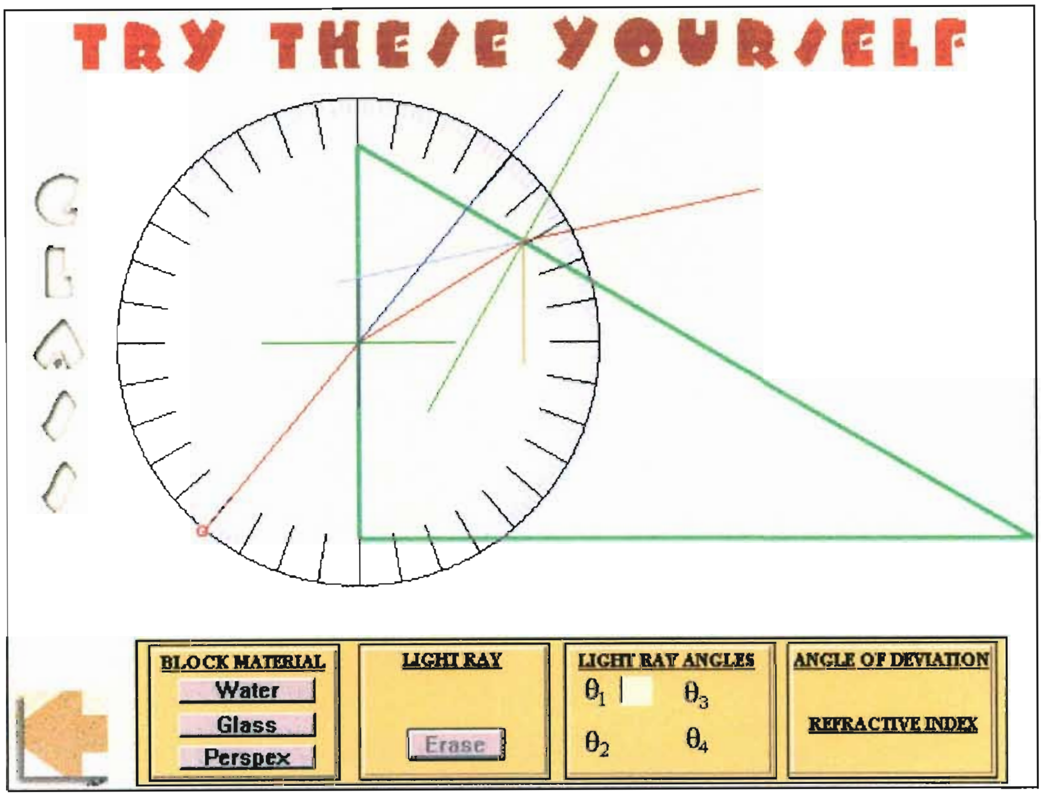


Figure 4.4: Display showing the path light travels through a glass prism

As the protractor can be "dragged-and-dropped" to any location on the screen, all angles including the angle of deviation can be measured (See Appendix 10 for sample code). From these calculations the student can determine the refractive index of the prism. Each angle, labeled θ_1 to θ_2, is allocated a text entry box (see Figure 4.4). Once the student has determined the individual angles, he or she enters it in these boxes. The computer evaluates the entry and, if it is correct, the student can enter the next angle into it's corresponding box. If the angle is incorrect, PULP displays a hint indicating how that angle is formed (Figure 4.5).

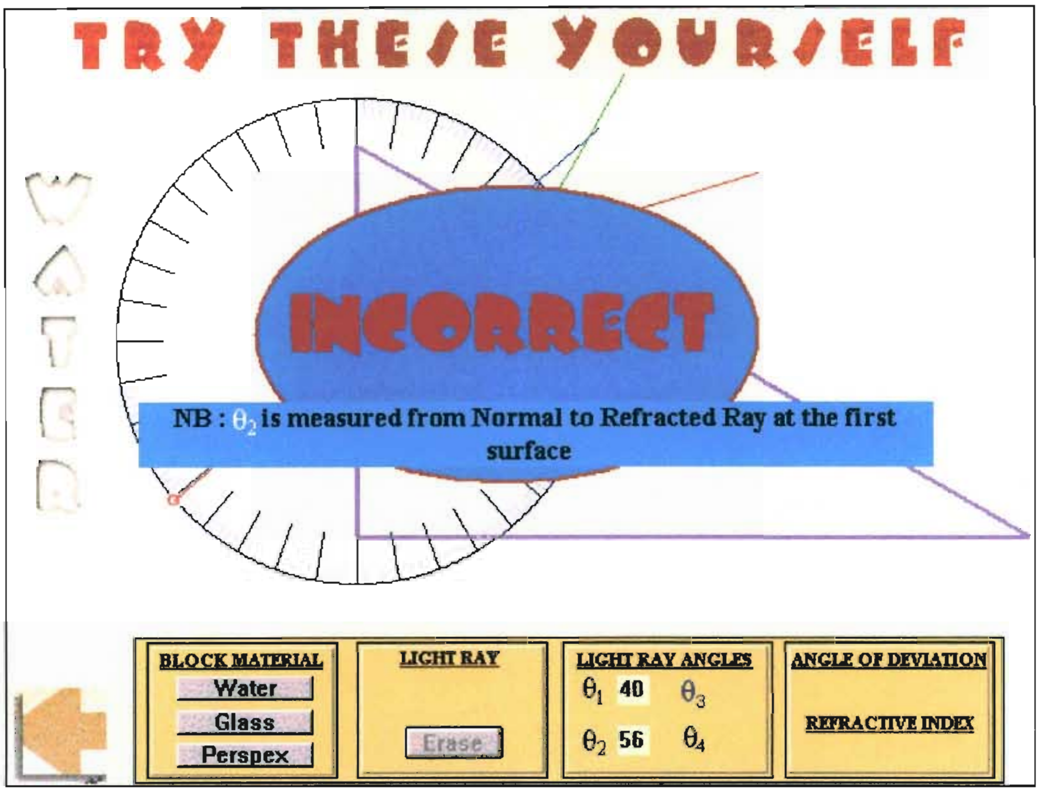


Figure 4.5: Hint given for incorrect angle of refraction in water prism

4.3 Assessment of students interaction with *Minimum Deviation*

The assessments for the *Minimum Deviation* section of the program were written at the same time as those for the basic measuring instruments (Appendix 4 and 5). In the first assessment, points were allocated for correctly calculating the angle of incidence (θ_3) at the second interface using Snell's law and using this value in conjunction with the refracting angle of the prism to calculate the angle of refraction (θ_2) at the first interface. Finally students calculate the angle of deviation by first using Snell's law to determine the angle of incidence.

The second assessment presents the student with the condition that light is travelling through a triangular prism at minimum deviation and is thus passing through the prism symmetrically. Points were allocated for correctly calculating the angle of refraction at the first interface and for correctly determining the refractive index of the prism. Results for the first and second assessment showing the number of correct responses, which are summarised in Table O1 and O2 respectively, were poor but not altogether unexpected. The learning of minimum deviation is dealt with in the first six months of the physics course and these assessments were conducted in the second half of the year. Many students had forgotten the theory associated with the Optics course and, although this section received favorable comments, there was no urgency to succeed in any of the assessments. However, interviews with students highlighted the misconceptions they hold with regard to Snell's law and minimum deviation. Many students did not understand what "light passing symmetrically through a prism" meant. These points will be used for future research and development of PULP. Interviews conducted with students are discussed below.

	Snell's Law at First Inteface (%)	Determining θ_2 (%)	Snell's Law at Second Interface (%)	Angle of Deviation (%)	Average Percentage Pass Rate (%)
First Assessment (n = 25)	22	3	3	3	9

Table O1: Summary of student results for first assessment

	Snell's Law at First Interface (%)	Refracting angle of Prism (%)	Average Percentage Pass Rate (%)
Second Assessment (n = 25)	3	3	3

Table O2: Summary of student results for second assessment

4.3.1 Interviews conducted with students after assessments

The consequence of a ray of light travelling through a prism at minimum deviation is that the ray passes through the prism symmetrically. Excerpts of interviews with students given below show that they do not understand what this symmetry means.

> *"Light passing through symmetrically means that this (indicating the refracted beam) cuts the prism equally...height above the this line is equal to the height below it."*

> *"Symmetry of light in a prism means that light goes straight through...angle of incidence (θ_1) is equal to the angle of emergence (θ_4)."*

By understanding what symmetry in a prism means will enable students to equate the angle of incidence with the angle of emergence as well as equating the angle of refraction at the first interface with the angel incidence at the second interface. This leads to the determining of the refractive index and the refracting angle of the prism. However, further interviews revealed that students also hold incorrect interpretations of Snell's Law and the refracting angle of the prism. Most students (80%) correctly identified what each variable in the Snell's Law equation represented, but as results from both assessments show, Table O1 and O2, students used these this equation incorrectly.

Snell's Law and the students' interpretation of the equation are discussed now. Students correctly identify the n_1 and θ_1 are the refractive index of air and angle of incidence respectively at the first interface. The subscript "1" for each variable is given to indicate that this is with regard to the first medium only and not the "first set of variables which goes on the left-hand side of the equation" as many students believed. Students had not realised that Snell's Law applied to two mediums, where the first medium was traditionally labeled as "1" and the second successive medium was labeled as "2".

A more accurate representation of Snell's Law should be:

$$n_x \sin\theta_x = n_{x+1} \sin\theta_{x+1}$$

Where x is taken to represent the medium light is currently travelling in and x + 1 taken to represent the medium light passes into.

Despite recognising the refractive index and angle of incidence at the first interface, many students took θ_2 to be the angle of emergence (θ_4) at the second interface. Many regard the refracted ray in isolation to the rays of incidence and emergence. As a result they answer the occurrence outside and inside of the prism as separate questions. Most students used Snell's Law to determine the interior angles of the prism and defined these angles as θ_2 being the angle of incidence at the first interface and θ_3 as the angle of emergence at the second interface. They also defined the refractive index at the first interface as that for air and the refractive index at the second interface as that for the prism. Results also show that the majority (95%) of the students did not know what the refracting angle of a prism is and many assumed that the prism had to be an equilateral triangle because "that's what was always given to us in lectures". The following interview, based on the second assessment (Appendix I2) illustrates these difficulties:

I: What does this exercise want you to determine?

S: The refractive index of the prism.

I: Why did you start with Snell's Law?

S: Simplest equation to start with.

I: Simple how?

S: Thought I knew what the variables were...now I know I was wrong...was not sure of the refracting angle of the prism.

I: What were you not sure of? What does the refracting angle of a prism mean to you?

S: Automatically assumed that this (indicating the refracted angle at the first interface) is the refracted angle of the prism...because no other angles are given.

4.3.2 Modifications to the program

Interviews with students revealed that most were able to define Snell's Law, but were not able to apply it to the assessment questions. It was that clear that students misinterpreted the change of media and regarded the equation to represent light when it entered and exited the prism only. The refracting angle of a prism, although not a new concept to the students, also caused much confusion. Many students assumed that the triangle was an equilateral triangle and thus the refracting angle was 60 degrees. In order to establish the correct use and definition of these terms, two separate pages were included into the Background Information of the program (Figure 4.6 and 4.7). It was decided not to include these hints into the body of the optics section as these may be overlooked by students. The first page (Figure 4.6) deals with Snell's Law and in the first instance shows light travelling from air into perspex. Here the interface along with all the angles is defined.

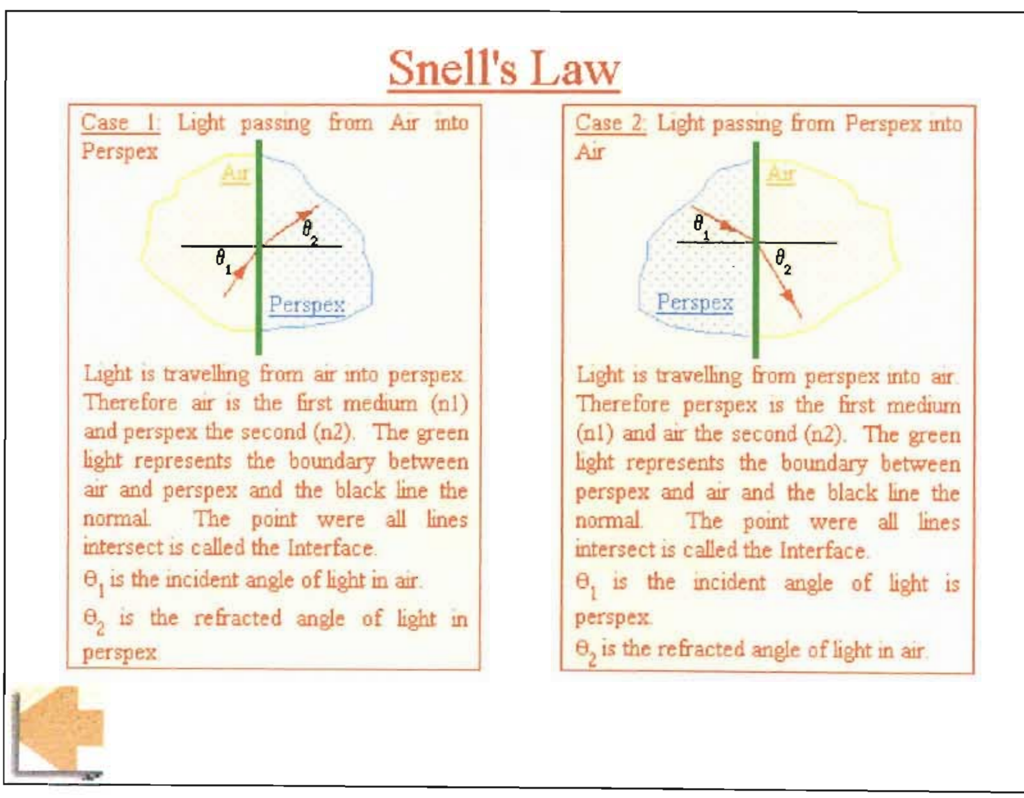


Figure 4.6: Additional page explaining Snell's Law when light travels from air into perspex and vice versa

The second case involves light as it passes from perspex into air. The second interface is defined and the angles are defined according to Snell's Law. By representing both cases and using the same variables in each case, students are shown that Snell's Law applies to two different mediums. Also the subscript given to each variable represents the first and second medium which light is travelling through and not the entry and exit points of light.

The second page (Figure 4.7) gives an explanation of the refracting angle of a triangular prism.

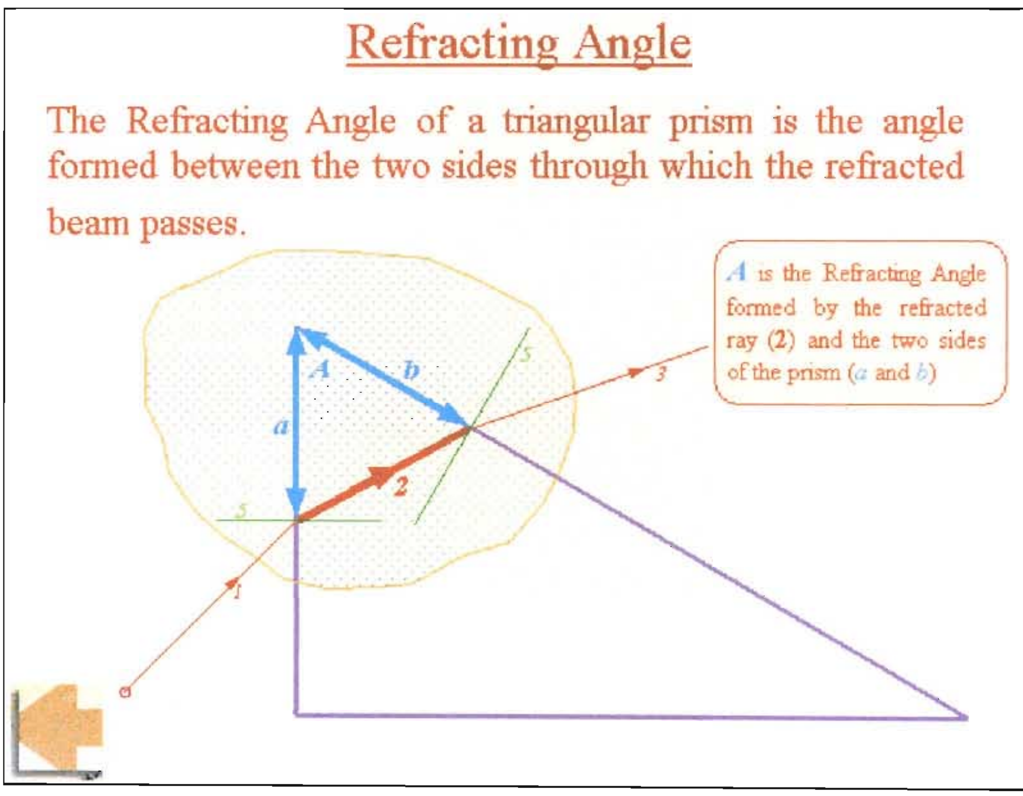


Figure 4.7: Explanation of Refracting Angle given in Background Information

It clearly shows which angle is the refracting angle and which sides of the triangle combine to form this angle. A concise definition of a refracting angle is also given.

4.4 Summary of *Minimum Deviation*

The ability to correctly reproduce an equation, such as the equation defining Snell's Law, should not be an indication that the student understands the theory relating to that equation. As the PULP investigation has shown many students use Snell's Law equation in both assessments because "it was easy and was given to us". They were also able to verbally define what each variable represented. However, students were not able to relate these variables to the triangular prism itself. The basic understanding of concepts such as medium, interface and symmetry is overlooked because of the faith students place in their ability to define equations mathematically.

It is evident from research conducted during the PULP simulation of minimum deviation of light passing through a triangular prism that in order to remove the misconceptions students have, clear definitions of these concepts must be given early in their introduction to optics. Furthermore, students need to see where an interface is located and what it means to say that light passes from one medium into another. Many students hold the misconception that symmetry implies equality in the sense that the height above the refracted beam is equally to the height below it. By showing students both a visual and mathematical representation of symmetry in terms of the triangular prism the programme has altered this belief.

In order for students to obtain success in more advanced questions in optics, a sound grounding of the basics is required. This may involve the inclusion of simpler questions that test these basics more rigorously. By having the student first identify each interface and medium and then solve the question will result in improving students' understanding and their success in optics.

CHAPTER 5

RESEARCH CONDUCTED ON THE EFFECTIVENESS OF A THEORY-BASED TOOL FOR INVESTIGATING STUDENT UNDERSTANDING OF ELECTRICITY

5.1 Introduction

The learning of electricity poses many conceptual difficulties to students due, in part, to the invisible nature of what is happening in an electric circuit. This makes electricity abstract and complex and has resulted in a wealth of research articles and possible remedial procedures. These include Ferguson-Hessler & de Jong (1987) who have shown that students display remarkable dexterity in solving complicated algorithms. However, few of these students have any success when asked to explain the same concepts qualitatively.

Further research in the field of electricity carried out by Fredette & Lochhead (1984), Carlton (1980), Cohen *et al* (1983) and McIldowie (1988) have highlighted the misconceptions students have when dealing with elementary concepts such as potential difference, current and resistance in simple electric circuits. Large-scale surveys of student ideas have been conducted by Maloney *et al* (2000) which consisted of a 32-question multiple-choice test administered to 5000 introductory physics students over a period of 4 years. Mulhall et al (2001) and Warnakulasooriya & Bao (2001) have suggested remedial procedures. The method discussed by Saxena (1992) proposed a three-phase remedial plan consisting of pre-tests, guided interviews and post-tests.

Evidence from the research articles listed above point to a commonality in the misconceptions students have in learning electricity. These misconceptions are not restricted to introductory physics students at tertiary institutions alone but also apply to school pupils and physics teachers (Cohen *et al*, 1983; McIldowie, 1998). A starting point for an analysis is a comparison between the language used by students and by physicists. Irrespective of how rigorously and unambiguously electrical concepts are defined, students attach their own meanings and understandings that are very different to the meanings shared by physicists (McDermott & Shaffer, 1992). Many students confuse the concept of electric current and electrical energy and often use these terms interchangeably (Shipstone, 1988). Consequently, students say that current, which is "stored" in the battery and may "rest" in the wires, is "used up" in a circuit and in a series combination of identical bulbs, the last bulb will receive the least amount of current and thus be the least bright. This is the most attractive explanation to students as for many the conservation of current is at variance with the fact that the battery must become "empty". Since batteries are seen as a constant source of current and since batteries go "flat" and need to be replaced, many students reason that current is consumed in the circuit (Duit & von Rhoneck).

Many students consider changes to elements in an electric circuit in isolation, believing that these changes have no consequences on the circuit as a whole (Cohen *et al*, 1983; Miller & King, 1993). They analyse these changes with respect to the elements alone or if the change affected a group of elements then they deal with each element sequentially in the circuit. However, a change made at one point in the circuit may result in changes at other points in the circuit. For example, consider parallel branches connected directly across the terminals of a battery and parallel branches connected elsewhere in the circuit. For parallel branches connected directly across the battery, any changes made in one branch has no effect on the second branch. However for parallel branches connected elsewhere in the circuit, a change in one branch affects the other branch. Students who view circuits in isolation claim that in the second circuit described above, a change in one branch has no affect on the second branch.

Another common idea held by students is that current is the primary concept in any electric circuit and that potential difference is regarded as a consequence of current flow and not as it's cause. This is due to students holding the idea that the battery is a constant current source and rather than a voltage source. Potential difference is viewed in abstraction and many relate current and potential difference by means of Ohm's law and rely on their mathematical capabilities to solve such problems.

Students also have difficulty distinguishing between potential and potential difference. Most often students do not realise that potential at a point in a circuit is merely a numerical value that may be determined by taking the negative terminal of a battery as frame of reference. The potential difference is the difference between two points in a circuit. For example Shaffer & McDermott (1993) showed that students were able to distinguish between these concepts by first knowing each operational definition and then by conducting experiments using a battery, a voltmeter and three identical bulbs connected in series. Measurements were first taken from the negative terminal of the voltmeter to the positive terminal of each of the bulbs, and then measurements were taken across the terminals of the bulbs. Students noted that each reading was approximately the same as the reading calculated for that bulb.

Two closely related difficulties experienced by students are identifying series and parallel connections and being able to distinguish between the resistance of an element and the equivalent resistance of a network containing that element. Most students can identify and resolve series and parallel connections if the circuit is presented in a conventional manner with parallel elements one above the other and series elements alongside each other. However many find it difficult when the circuit is drawn in an unconventional manner with multiple series and parallel connections. Most students rely on the physical lines connecting the elements in a circuit diagram rather than what electrical connections are represented by those lines. McDermott & Shaffer (1992) has stated:

> *"Students often fail to extract the critical features of a series or parallel connection that would enable them to identify such connections in complicated circuits. The term series often evokes the idea of sequentiality, rather than a specific type of connection. The term parallel often retains a geometrical rather than electrical interpretation."*

For many students using a mathematical equation to solve equivalent resistance is relatively simple. However few realise that the calculation of equivalent resistance is useful for finding the total current or potential difference in the circuit, and that the resistance of an individual element must still be used to determine the current through or potential difference across that element.

Research (e.g. Kibble, 1999) has also shown that students find it difficult to construct a physical electrical circuit by studying the circuit diagram. One circuit may be drawn in many different ways and elements such as the ammeter and voltmeter are represented differently in the diagrams. The connection between the leads in the diagram may differ greatly from the connecting leads of the actual circuit. As a result, there is little correspondence between what is drawn and what is physically connected. Students tend to focus their attention on the physical characteristics rather than the electrical connections.

5.2 Description of the design structure of *Electrostatics*

As all students using PULP are first year introductory physics students who have volunteered to use the program, an emphasis in the design process was placed on covering the syllabus being taught in formal electricity and magnetism lectures, and in particular the electricity section. The lectures on electricity cover, amongst others, the topics of electrostatics, capacitors and resistors, and electromotive force. These are the subsections dealt with in the *Electricity* section of PULP. The focus of *Electricity* has been placed on improving students' understanding of the theory related to each subsection and, in contrast to the other sections in the program, there are no simulations. In order to provide a complete understanding of *Electrostatics*, each section is structured sequentially beginning with *Definitions*, *Worked Examples* and finally *Try These Yourself* (Figure 5.1). Although each section may be accessed randomly depending on the student's confidence in the various sections, they are encouraged to work through each section sequentially.

Figure 5.1: Electrostatics sub menu

Students begin by reviewing the operational definitions most commonly associated with electrostatics in the *Definitions* section (Figure 5.2). These definitions are frequently tested in examination and test questions, where the student is either asked to state the definitions or where the student has to use the mathematical implication of the definitions. The definitions are given in a written description format and in some cases accompanied by the relevant mathematical equations.

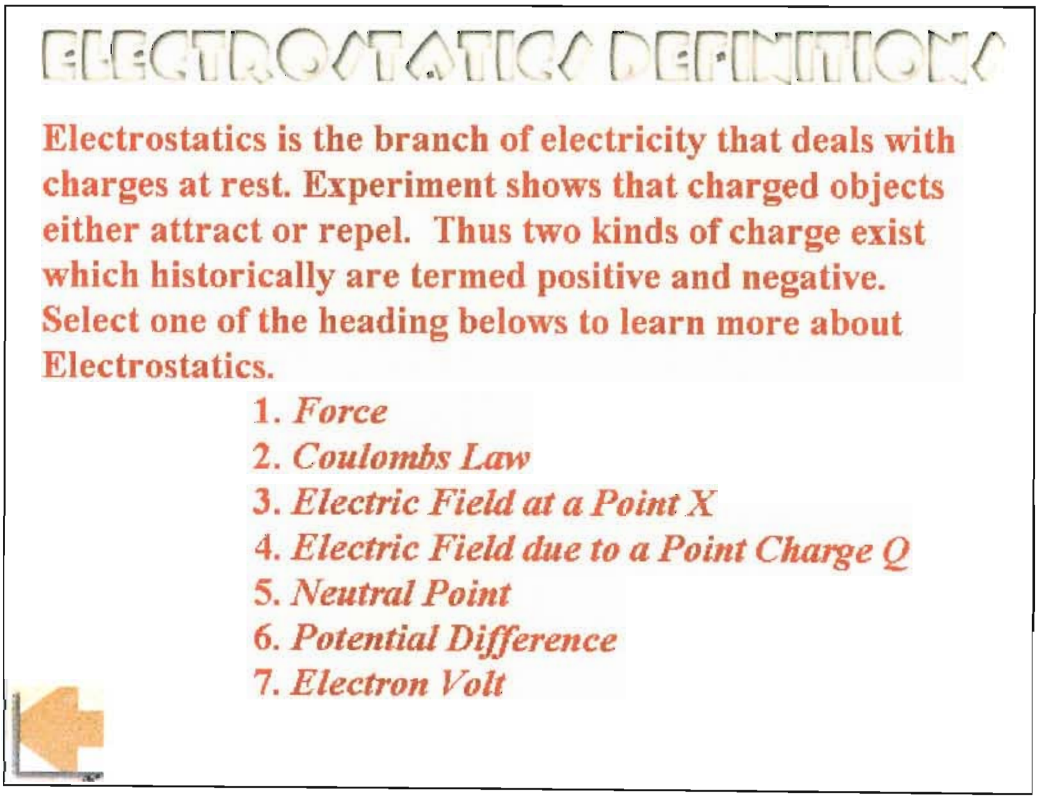


Figure 5.2: Definitions window of Electrostatics

The provision of a definition resource serves as a foundation for the concepts students will encounter later in the given examples (*Worked Examples*) and the self-assessment section (*Try These Yourself*). Its purpose is also aimed at boosting the confidence of students when they attempt the self-assessment section, as they will know exactly what is being discussed and being asked of them to calculate. It also draws their attention to key differences between related concepts such as electric field at a point and electric field due to a point charge (Shaffer and McDermott, 1993). The definitions may be accessed at by means of navigation icons at the bottom of the displayed screen.

Students often misinterpret examination and test questions, in part due to a lack of understanding of the concepts being tested and because of the difficulty they have in understanding the language being used (Campbell *et al*, 200). In order to address these difficulties, the examples in the *Worked Examples* section of *Electrostatics* (Figure 5.3) are based on typical examination questions and show the student the context in which concepts are tested and applied. Each worked example has an explanation using the relevant theory as well as the calculation (equation, use of constants, etc) required to solve the question.

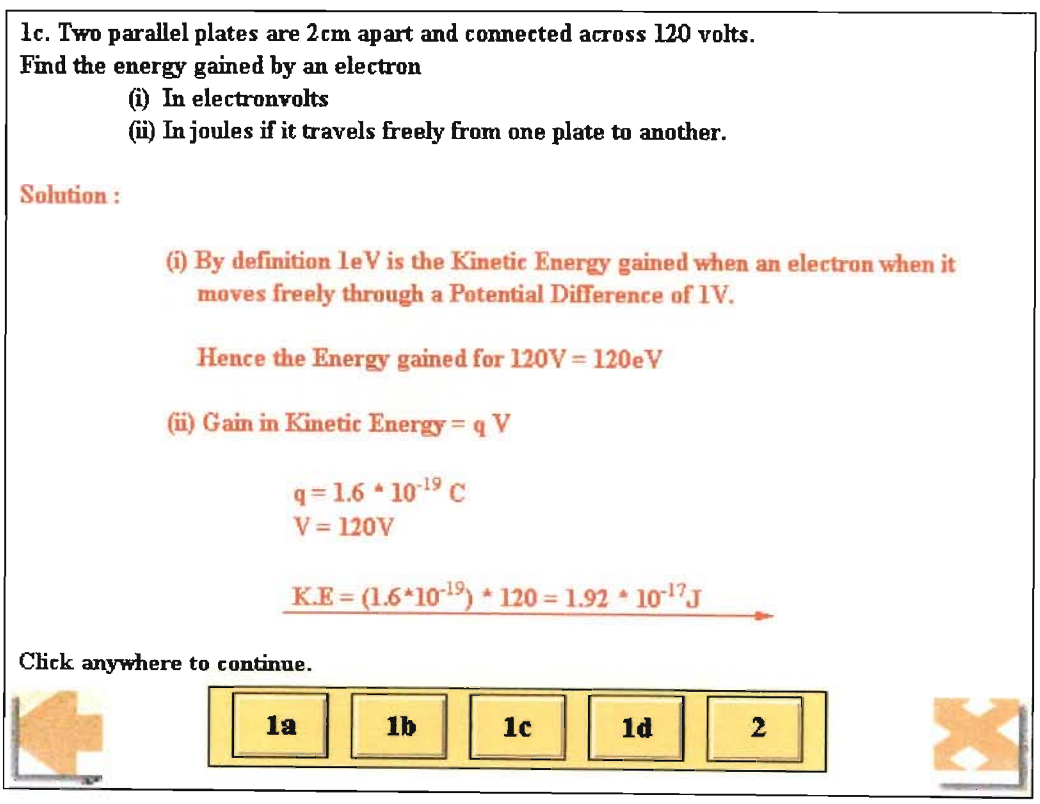


Figure 5.3: Sample question. Questions 1a – 1d are follow on type questions

The *Worked Examples* section is made up of two examples, although the first example is divided into four sub-questions (questions 1a to 1d in Figure 5.3 above). Often in order to solve the question, a number of secondary calculations needs to be done first. The method used in these examples illustrates how a question may be broken into components in order to solve it. It shows the student that in order to answer the question, one may need to find intermediate results first.

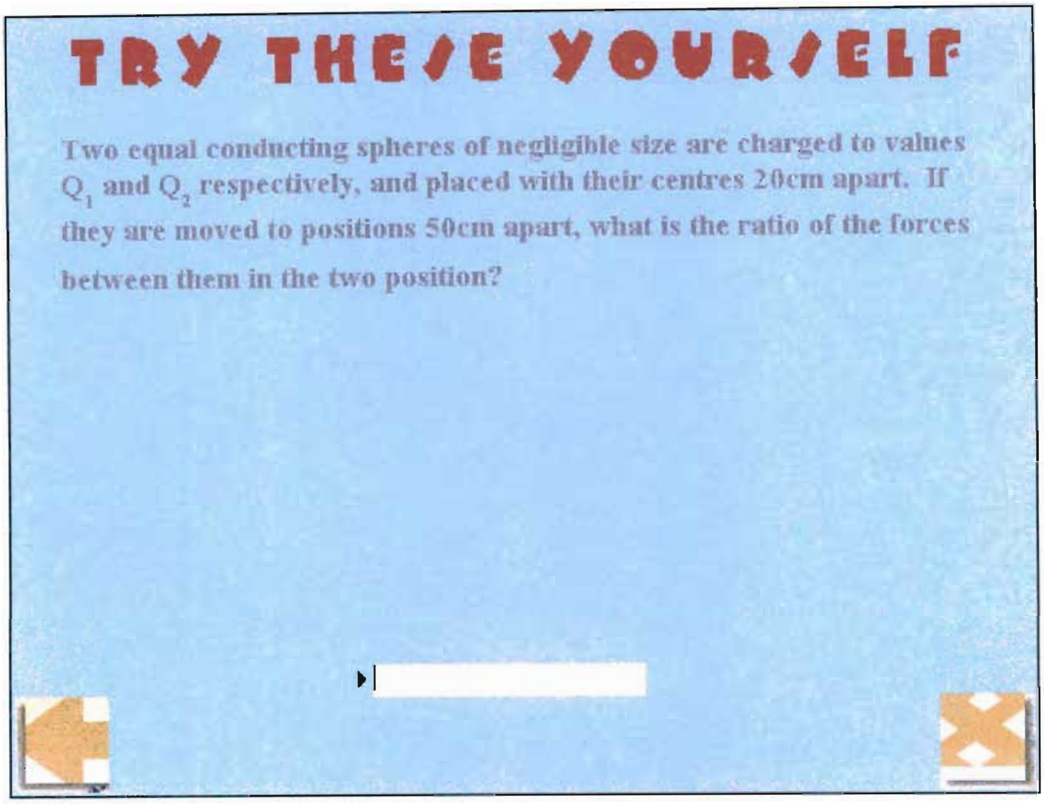


Figure 5.4: Randomly generated question from Try These Yourself section

Finally, students attempt the self-assessment section that tests the students' understanding of electrostatics (Figure 5.4). The questions in this section are from past examinations and are randomly generated from a database. This ensures that students rely on their understanding rather than their ability to memorise answers. The *Try These Yourself* section requires the student to do the calculation manually (i.e. using pen, paper and calculator) and then enter only the calculated answer into the program. Each time the student enters an answer, the program immediately checks the result and returns a response of either correct or incorrect. If the answer is correct, the next question is generated. If the answer is incorrect, the program gives the student a hint. There are three attempts to each question and two hints. The first hint is general and is the same for all the questions. It advises the student to consider the given information and recall the relevant theory and equation. This is a ploy to simply get the student to re-think and re-do their problem. The second hint is specific to that question and provides the physics concept being tested which tries to assist the student to answer the question correctly. The final incorrect entry results in the computer displaying the right answer and advising the student to review the electrostatic section. A detailed solution to the problem is not included in the final hint as it was decided that students may forgo the effect of attempting the question themselves, and simply "trick" the computer into displaying the answer.

5.2.1 First assessment of students after interaction - *Electrostatics*

The first assessment of *Electrostatics* consists of three questions (see Appendix 6) and is predominantly mathematically orientated. As formal lectures on electrostatics had just began (a week before the first assessment) it was suggested that this assessment test the student's ability to define Coulomb's Law along with the units associated with each variable and to find the ratio between the electrostatic force and the gravitational force. Each group which consisted of first year introductory physics students (25 PULP students and 45 NON – PULP students) had one week to prepare for the test. During that week, PULP students had one 45 minute period in which to use the *Electrostatics* section of the program in the presence of an instructor. The purpose of the instructor was twofold – to gauge the students' reaction to the physical appearance and general functionality of the program and to interview students on their understanding of the content in the program.

An analysis of Question 1 was based on the following criteria:

(a) Did the student use the correct equation (EQ1)?

(b) Was the explanation accurate (EX1)? The degree of accuracy was measured by the inclusion of key phrases such as: "stationary point charges" and "along the line joining the charges", and key words such as: "magnitude" and "direction".

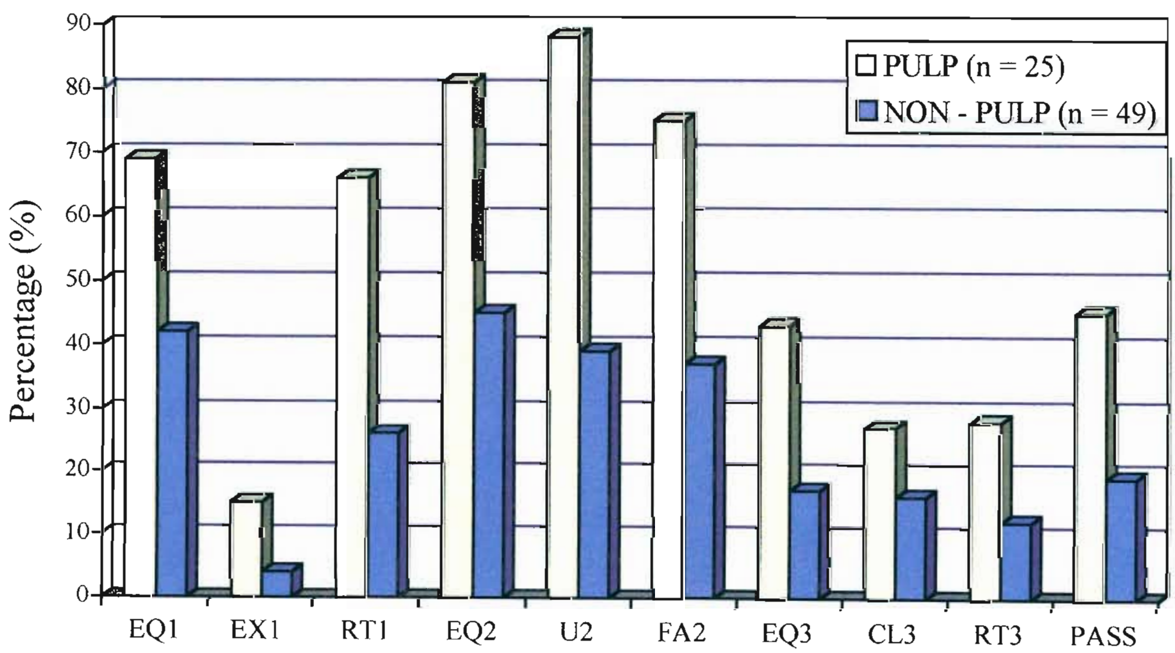
(c) Did students identify correctly which magnitudes were proportional and which were inversely proportional (RT1)?

Question 2 tests whether the student knows the correct equation (EQ2), the units (U2) associated with each variable in that equation and their final answer (FA2). The student's ability to calculate Gravitational Force and Electric Force is tested in the last question. Marks are allocated for using the correct equations (EQ3), mathematical manipulations (CL3) and finding the correct ratio (RT3).

The results of the first assessment are summarised in Table E1 and Graph 5.1.

	Question 1			Question 2			Question 3			Pass (%)
	EQ1 (%)	EX1 (%)	RT1 (%)	EQ2 (%)	U2 (%)	FA2 (%)	EQ3 (%)	CL3 (%)	RT3 (%)	
PULP Students (n = 25)	69	15	66	81	88	75	42	27	28	45
NON – PULP Students (n = 49)	42	4	26	45	39	37	17	16	12	19

Table E1: Summary of first assessment of PULP and NON – PULP students



Graph 5.1: Summary of student performance on first assessment

5.2.1.1 Discussion of results from first assessment

Research has shown that many students rely on mathematical equations in order to explain the theory of physics concepts (Ferguson-Hessler & de Jong, 1987). Results from this assessment show that most students (69% and 42% for PULP and NON-PULP students respectively) were able to give the correct equation but fewer (15% and 4%) were able to provide the correct explanation for Coulomb's Law. Some (12%) did not include an equation in their explanation. Coulomb's Law states that the magnitude of an electric force exerted between two stationary charges is directly proportional to the magnitudes of each charge and inversely proportional to the square of the distance between them. However, of the students who used the correct equation in defining Coulomb's Law, most (94%) based their explanation solely on the mathematical operations performed on each variable. For example, a typical explanation (by "typical" it is implied an explanation which generally reflects the type of responses received) of Coulomb's Law based on the equation is:

> *"It is the product of 2 charges a certain distance apart which is inversely proportional to the square of the distance between."*

Little attention is paid to stating that each charge is stationary and that the force acts along a line between each charge. Students also omit the fact that it is the magnitude of each charge and the magnitude of the force that is determined by Coulomb's Law. If a student did include a discussion of force in their definition then it was merely by stating that "like charges attract and unlike charges repel".

Question 2, although mathematical in nature, tested the students' knowledge of the unit associated with each variable. Results show that 81% of the PULP students had used the correct equation and 88% were able to derive the units for the proportionality constant correctly, whereas only 45% of the NON-PULP students used the correct equation and even fewer (39%) were able to derive the units. Interviews with PULP students after the first assessment showed that all students attributed their success to the fact that the program dealt with Coulomb's Law in a "very understandable and easy way".

5.2.2 Second assessment of students after interaction - *Electrostatics*

The second assessment is an analysis of the class test given to all students by the Physics department as part of their course in electricity. The results of this test contribute to the students' class mark that determines whether a student has been admitted into the year-end examinations. The lecturer concerned with teaching the introductory electricity course advised the students well in advance of the date as well as the sections that were to be covered in the test. The class test was written five weeks after the first assessment of electrostatics was conducted and two weeks after the PULP sessions had ended. During the five-week period, students had three 45-minute sessions in which to interact with the program. Of the three sessions, one focussed on the *Electrostatics* section of the program. The *Capacitors* and *Resistors* sections were studied during the other two sessions. During the two weeks after the last session of PULP, volunteer students had the option of using the program without the supervision of the instructor. Appendix 9 shows questions from the class test that are relevant to this project.

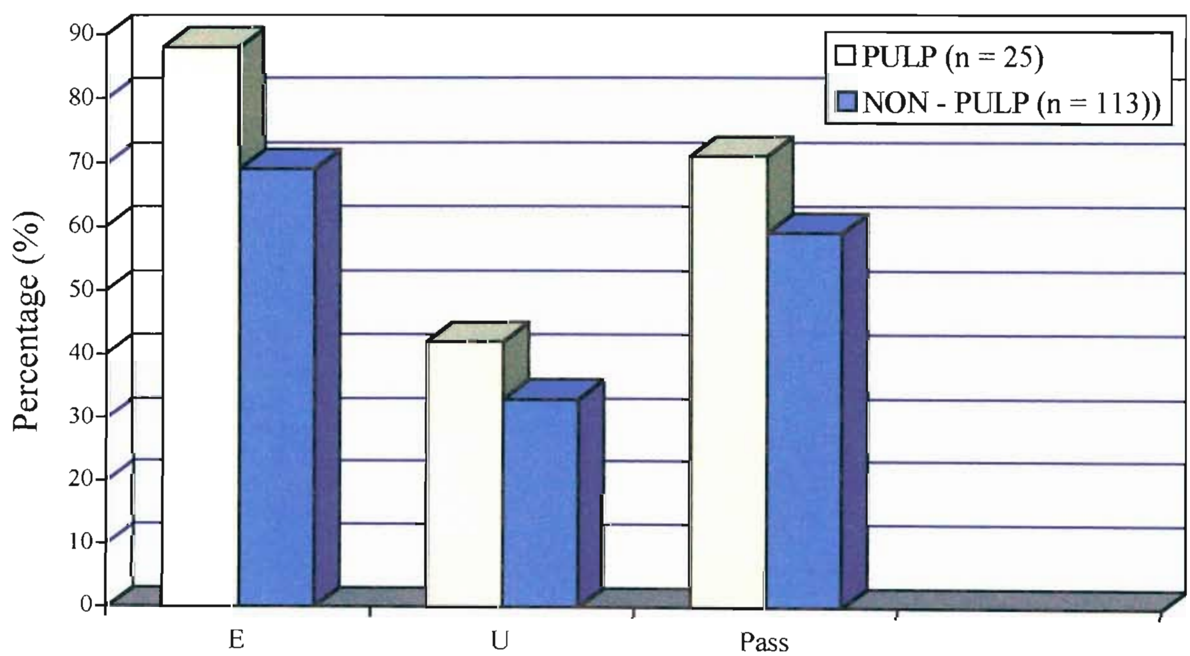
Question 1 focused on the students' ability to reproduce the equation defining the magnitude of an electric field of a point charge, and to define the units associated with each variable. This is similar to the questions (Question 1 and 2 in Appendix 6) answered in the first assessment as it tests the students' ability to identify concepts and use the appropriate equation. Students in both groups performed poorly in defining the units of an equation. As one student said:

> *"I have problems keeping concepts and equations straight in my head, knowing the units too is just to much to handle."*

In order to address this, the hints in the *Try These Yourself* section states the units for the equation being tested in that question. The results of the second assessment are shown in Table E2 and Graph 5.2.

	EQ (%)	U (%)	Pass (%)
PULP Students (n = 25)	88	42	71
NON – PULP Students (n = 113)	69	33	59

Table E2: Summary of second assessment of PULP and NON – PULP students



Graph 5.2: Summary of student performance on second assessment

5.2.3 Summary of *Electrostatics*

Results of the second assessment show that PULP students, after only one session with the program, achieved a higher overall success rate as compared to the NON-PULP students. Interviews showed that many students feel "swamped" with the theory and equations dealt with in electrostatics. They feel that textbooks and lecture notes do little to ease the confusion they have with seemingly related concepts such as potential at a point and due to a charge. All PULP students agreed that the definitions and worked examples in the Electrostatics section improved their understanding because as one student said:

> *'...when I got stuck with a word or term I didn't know, I could just click on definitions and find that word...the explanation and units helped me a lot unlike the notes and text where I had to search for the answer and then put the answer together myself."*

5.3 Description of the design structure of *Capacitors*

Although much research into the learning of electricity has centered on students' understanding of electric circuits containing resistors, little has dealt with the difficulties related to circuits containing capacitors. Capacitor circuits are taught at first year level both in formal lectures and in the laboratories. Although similar in theory to resistor circuits (in a resistor circuit current, potential difference and resistance are key elements whereas in capacitor circuits charge, capacitance and potential difference are highlighted properties) it is the subtle differences that cause difficulty. In a capacitor circuit the calculation of the reciprocal equivalent capacitance for capacitors in series is determined by the sum of the reciprocal of each of the capacitors, while the equivalent capacitance for capacitors in parallel is determined by the sum of the individual capacitors. The opposite is true for resistors. In a series resistor circuit, the equivalent resistance is calculated by finding the sum of individual resistors, whilst in a parallel circuit, the reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the individual resistors.

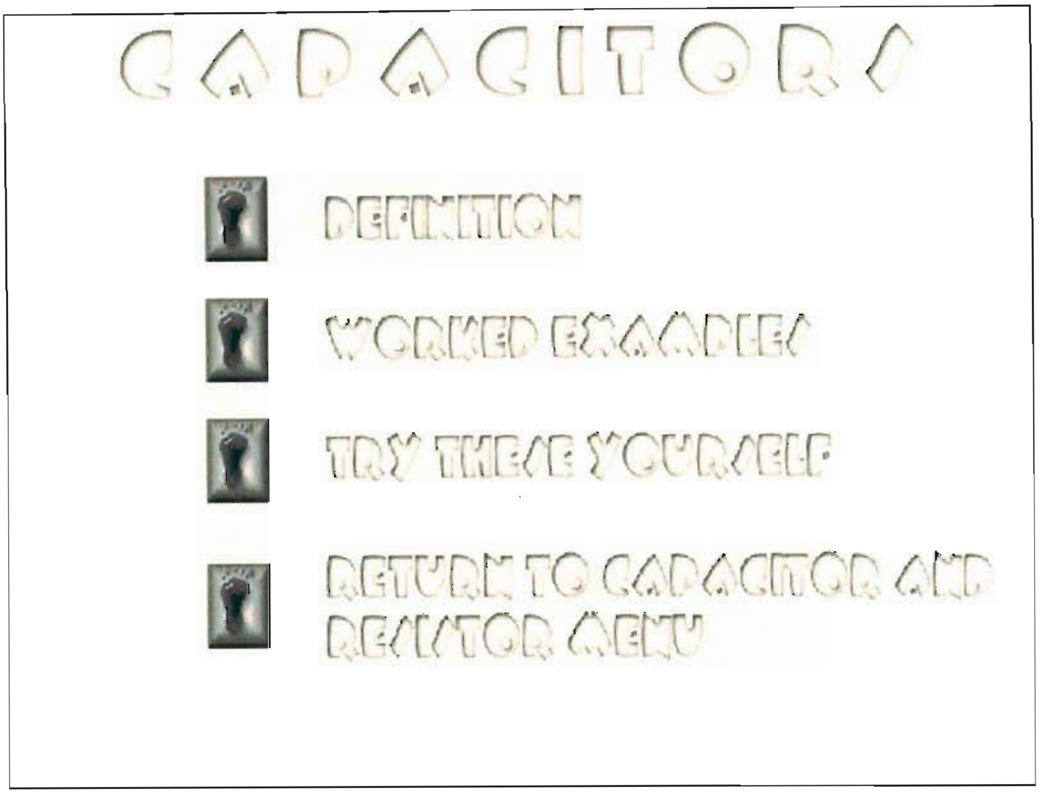


Figure 5.5: Display window of capacitors submenu

In order to address these difficulties PULP structures instruction (Figure 5.5) by beginning with a description of a capacitor (including the equation and units) and of the properties of capacitors in a series and parallel circuit configuration shown in Figure 5.6.

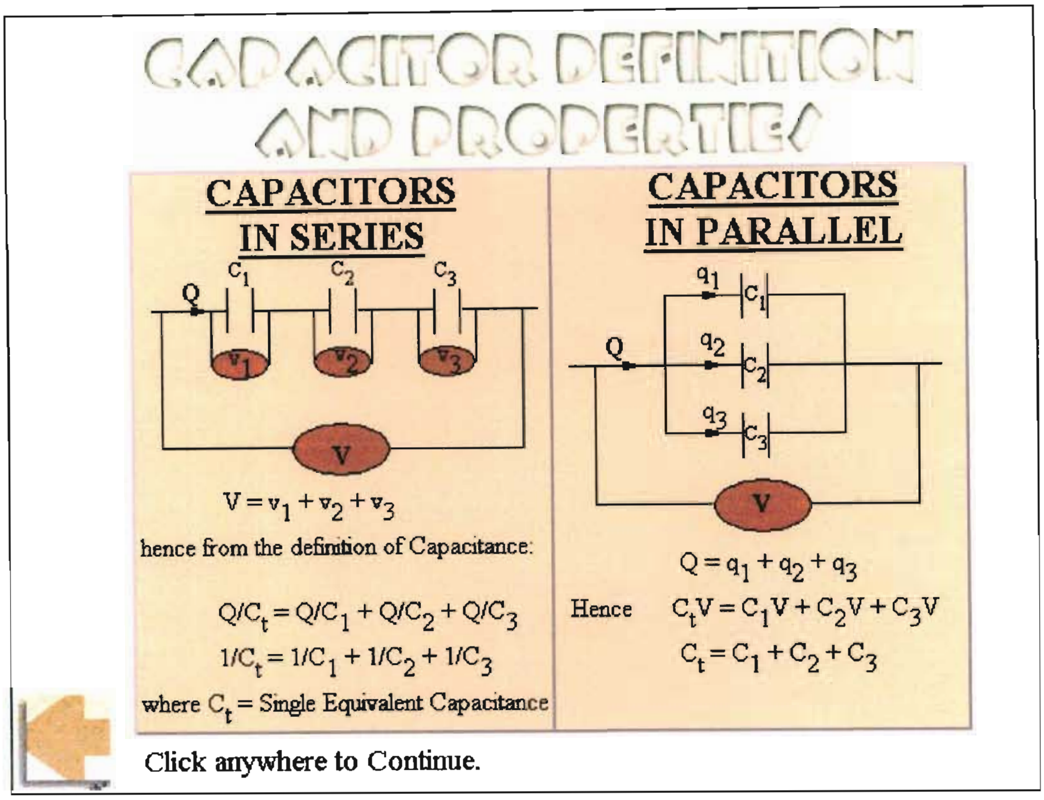


Figure 5.6: Properties of capacitors in series and parallel

To immediately illustrate the differences between capacitors in series and capacitors in parallel both definitions are displayed alongside each other. The diagram for the series circuit has three capacitors (C_1, C_2 and C_3) in series and shows the student that the charge (Q) remains constant as it is stored in each. The potential difference across each capacitor is different and is represented by v_1, v_2 and v_3. However the sum of these individual potential differences is equal to the total potential difference (V) in the circuit. This leads to the equation showing that the reciprocal equivalent capacitance of a series circuit is equal to the reciprocal of the individual capacitors. For the parallel circuit, three capacitors (C_1, C_2 and C_3) are shown to have individual charge (q_1, q_2 and q_3) passing through each of them whilst the potential difference (V) is common to all. The sum of the individual charges is equal to the total charge in the circuit and the equivalent capacitance of a parallel circuit is shown to equal to the sum of the individual capacitors.

As with other sections in the program, *Capacitors* aims to reinforce instruction with example. The *Worked Examples* section in *Capacitors* is a series of questions taken from past examinations and tutorials which students from previous years found difficult to answer. There are two questions in the *Worked Examples* section that can be accessed randomly. Question 1 illustrates the calculation of the equivalent capacitance by resolving a multi-branched circuit that has both series and parallel connections. The solution is given in step format (i.e. step1, step2 etc) and at each step the type of connection (either series or parallel) is identified. Once the type of connection is identified, the relevant equation is used.

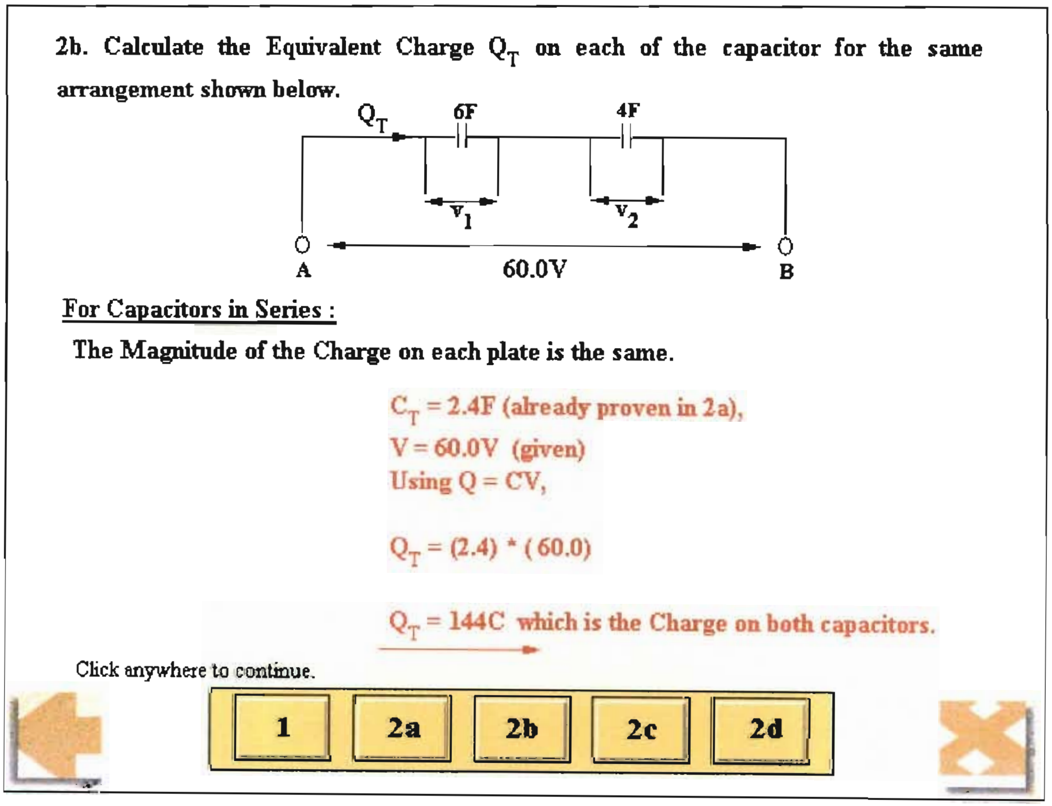


Figure 7.7: A capacitor example showing the result from question 2a being used in the calculation to solve question 2b

Question 2 is made up of four sub-questions. The result obtained from one question is used in the calculation for the next question as shown in Figure 7.7, where the result obtained in question 2a is used in the calculation of question 2b. This "follow-on" sequence show students that sometimes an intermediate result is required in the solution but is not directly asked for in the question.

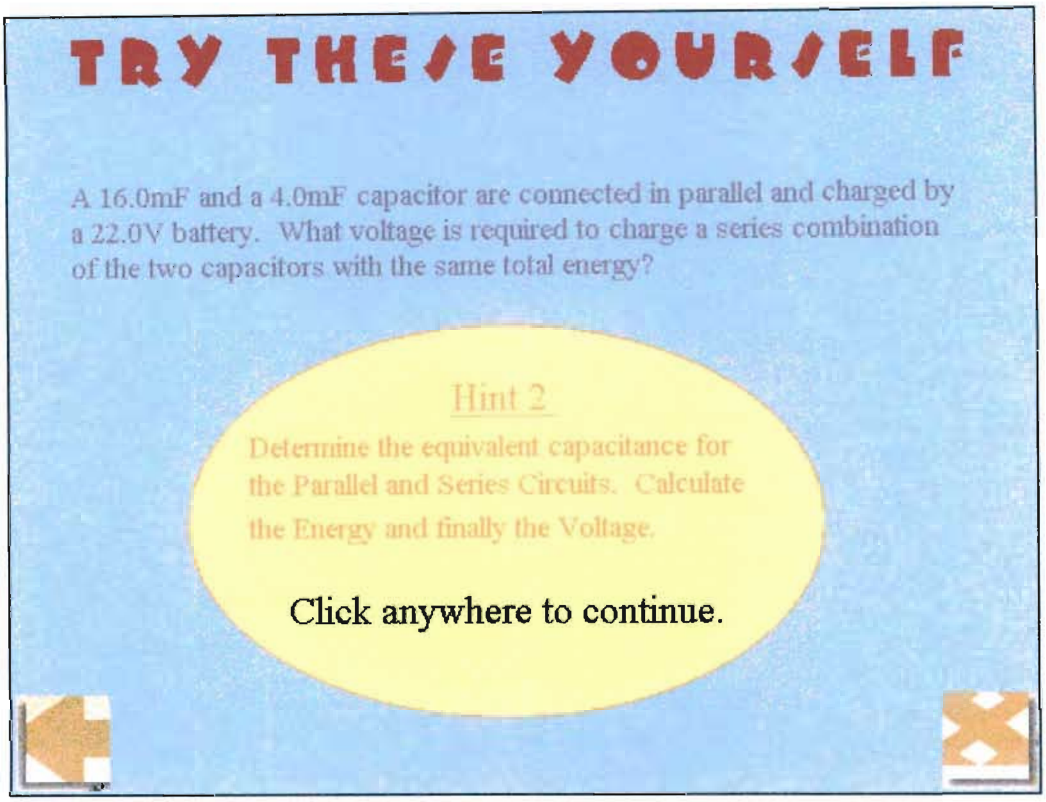


Figure 7.8: Second hint given for self-assessment section of Capacitors

Capacitors have a database of questions, which are randomly selected and are used by students to gauge their understanding. The student has three attempts at each question and hints are given for the first two incorrect answers (Figure 7.8). The *Try These Yourself* section contains questions dealing with equivalent capacitance of non-conventional circuits i.e. circuits where the capacitors are not along side each other or one above the other as for series and parallel circuits respectively. There are questions that test the students' understanding of charge on a single capacitor if the total charge is given as well as calculations on total energy. Some questions (such as the question given in Figure 7.8) give the student one circuit and then call for a result if the arrangement of that circuit was changed. By including an array of questions, the *Try These Yourself* section gives students a broader understanding of capacitors and tests both their mathematical skill and conceptual ability. Students are also told that questions in this section are taken from past examinations, and this creates urgency in them to succeed, as their performance in the self-assessment section is an indication of how well they will perform in tests and in the examination. The use of test and examination questions ensures that an interest in the section is maintained and retains the relevance of the whole program.

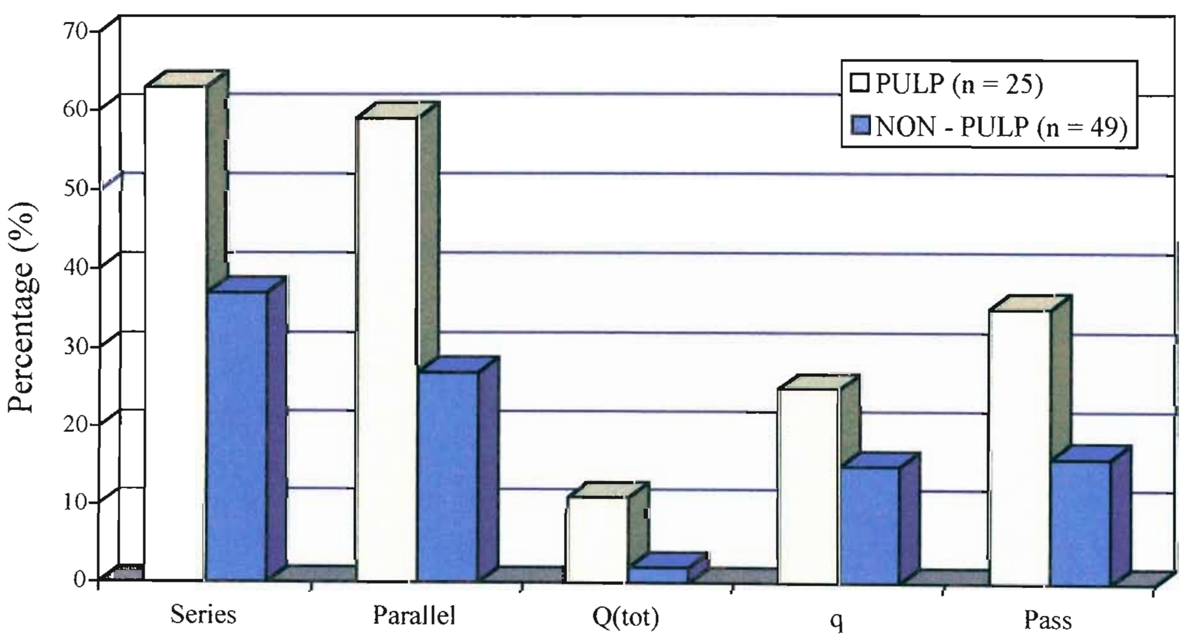
5.3.1. First assessment of students after interaction - *Capacitors*

All students (PULP and NON-PULP) were given a week in which to prepare for the capacitors test. PULP students, in addition to formal lectures and tutorials given by the department, had one 45-minute session to use the *Capacitors* section of the program. As this was the first interaction students had with this section, the instructor spent a short period of time (two minutes) discussing the dynamics of *Capacitors*. In cognisance of previous research on electricity, the instructor emphasised the importance of differentiating between parallel and series capacitor circuits, by drawing the students' attention to the *Definitions* section (Figure 7.6). Students were encouraged to redraw circuits so that it resembled conventional circuits, with which they were more comfortable and to indicate on the diagram where series branches began and ended and where parallel branches began and ended.

The test question (Appendix 7) administered to both groups was adapted from a previous final year examination paper ensuring that the level of difficulty was comparable to questions students would answer in tests and examinations. As the question was designed by an independent source, any possibility of bias on the part of the instructor was removed. The circuit consisted of a series and parallel combination of capacitors. The orientation of the circuit was altered so as not to represent a conventional circuit, as students are accustomed to capacitors being drawn from left to right in the plane of the page. By drawing the capacitors from top to bottom in the plane of the page, the question is testing the students' ability to recognise a series and parallel connection and to then calculate the equivalent capacitance in the circuit. The charge on each capacitor was required and this tested whether the student understood that potential difference across a parallel arrangement is constant and that charge in the circuit splits at the branches leading to the individual capacitors. Table E3 and Graph 5.3 shows the results of the first capacitors assessment.

	Question 1		Question 2		Pass (%)
	Series (%)	Parallel (%)	Charge Total (%)	Individual Charge	
PULP Students (n = 25)	63	59	11	25	35
NON – PULP Students (n = 49)	37	27	2	15	16

Table E3: Summary of results for first capacitor assessment



Graph 5.3: Summary of first assessment for capacitors

5.3.1.1 Discussion of the results from first assessment

Sixty three percent of PULP students correctly identified and calculated the capacitance for the capacitors in series. One, of the thirty seven percent of students that answered this part of the question incorrectly, assumed that the "C" (which is the charge in the circuit) in the equation "Q = CV" (which is the equation used to calculate capacitor problems) represented capacitance. A majority of the 37% of students identified the series and parallel capacitors correctly, however in their calculation they resolved the series capacitors by finding the sum of the individual capacitors. They then used the reciprocal of this result and added it to the reciprocal of the third capacitor in order to find the equivalent capacitance. This showed that students confuse the properties on capacitance with the properties of resistors in parallel and series.

A further observation from the analysis showed that in the calculation of equivalent capacitance for capacitors in series, students often equate the sum of the reciprocal capacitors to the equivalent capacitance instead of the reciprocal of the equivalent capacitance. In their calculation of the charge stored in each capacitor, all students (those who had found the correct equivalent capacitance) were able to calculate the charge stored in the 4μF capacitor. However a large percentage of these students used the same method to calculate the charge passing through the capacitors in series, namely they found the product of the individual capacitors and the potential difference. This results in answers of 1000μC and 500μC for the 10μF and 5μF capacitors respectively. Although students identified that these capacitors were arranged in a series combination, they viewed each capacitor in isolation of the other and so charge at each capacitor would be different and warranting individual calculations.

An interview by the instructor (I) with a student (S) regarding charge is given below and represents the general conception held by students:

I: Suppose you have two capacitors, C_1 and C_2 say, which are connected in series across a potential difference (V) and charge (Q). What will be the charge on C_1 and C_2 respectively?

S: Well they will be equal. Both capacitors will have a charge of $\frac{\mathbf{Q}}{\mathbf{2}}$.

I: $\frac{Q}{2}$? Why this value?

S: Because the sum is equal to Q.

I: What happens if C_1 is equal to C_2? What is the charge then?

S: It would be 2Q...two capacitors are equal and combine to form a big charge 2Q.

I: But the total charge in the circuit is Q. Where does the other Q come from?

S: From the second capacitor (pointing to C_2)...Capacitors store charge right, so after awhile it gives this charge back to the circuit.

I: OK! What happens if C_1 and C_2 are not equal?

S: Have to have the ratio...ratio of total volts...suppose we have Q_1 and Q_2 then the volts for Q_1 will be $\frac{V_1}{V_{TOT}}$ and the volts for Q_2 will be $\frac{V_2}{V_{TOT}}$.

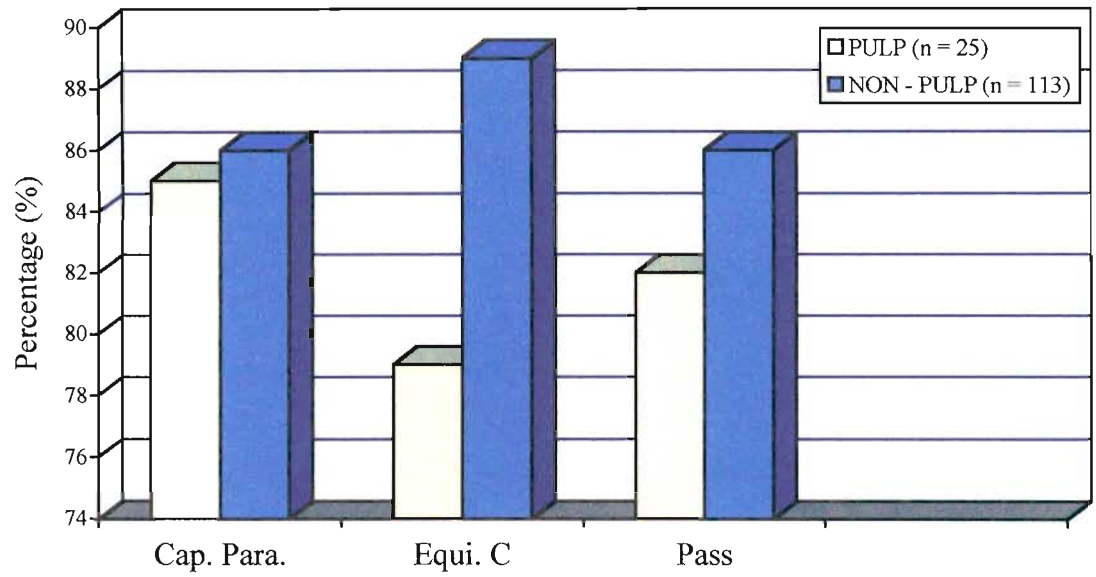
Further discussion revealed that the student had confused charge with capacitance and using $C = \frac{Q}{V}$ had taken C to be inversely proportional to V resulting in the "ratio of total volts". The role of capacitors also seem to have confused students as the interview given above indicates.

5.3.2 Second assessment of students after interaction - *Capacitors*

Students were asked to determine the equivalent capacitance in the circuit (Appendix 9). This circuit is similar to the one given to students in the first assessment, with the differences being the value of each of the capacitors, the orientation of the entire circuit and the location of the parallel and series branches. Results of the second assessment show significant gains in both groups with an improvement in the calculations in resolving the parallel capacitors into a single capacitor and the equivalent capacitance of the entire circuit. Analysis shows that many PULP students included a diagram in their answer. Indicated on this diagram were "asterisks" which was meant to indicate points of a series branch and points of a parallel branch. A major cause of incorrect responses was due to calculation errors. Table E4 and Graph 5.4 presents the results of this assessment.

	Capacitors in Parallel	Equivalent Capacitance	Pass (%)
PULP Students (n = 25)	85	79	82
NON – PULP STUDENTS (n = 113)	86	89	86

Table E4: Summary of second assessment for Capacitors



Graph 5.4: Summary of student performance on second assessment for capacitors

5.3.3 Summary of *Capacitors*

The underlying difficulties experienced by students are the concepts of charge and potential difference for parallel and series arrangements. Students treat each capacitor in the circuit as individual components and as such find it necessary to calculate the charge stored in each capacitor in series rather than stating that the charge for each such capacitor is the same. A large percentage of the students also fail in their calculations because they confuse the properties of resistors in series with capacitors in series. As such they find the equivalent capacitance to be the sum of the reciprocal of the individual capacitors. This indicates that if the student has a weak understanding of capacitors they will revert to their understanding of resistors in order to solve the question. As the principles of both resistors and capacitors are similar, they assume that the properties are the same as well. By continuously directing PULP students to the definitions of capacitors in the program, the properties of each circuit was reinforced and this led to an improvement of their understanding and success in capacitor-related questions as shown by the results from both assessments.

5.4 Description of the design structure of *Resistors*

The definition of the resistance of a resistor is taken from Ohm's Law and is given as being equal to the ratio between the potential difference across and current through the resistor. As much confusion has centered on circuits with resistors connected in series and/or parallel (McDermott & Shaffer, 1992), PULP begins the *Resistors* section with a clear illustration of the properties associated with these two arrangements (Figure 5.9).

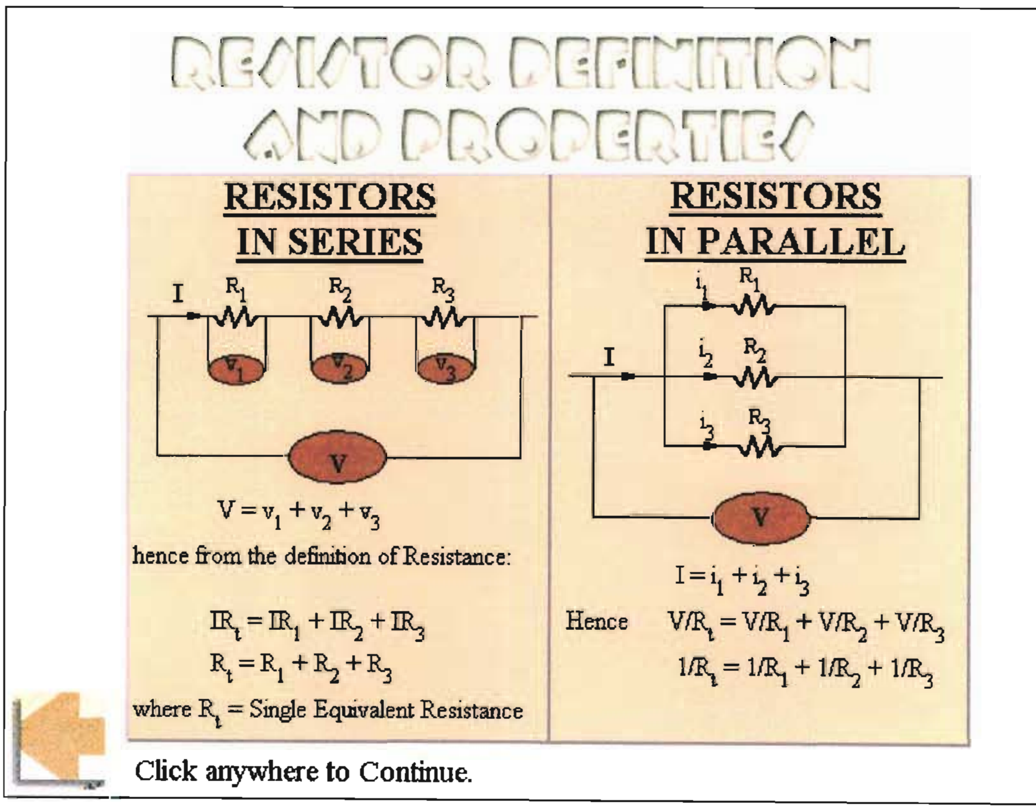


Figure 5.9: Properties of resistors in series and parallel

For resistors in a series circuit, the current (I) passing through each resistor is the same. If each resistor has different ohmic value then the potential difference (v_1, v_2 and v_3) across each resistor is different. If all resistors are equal (i.e. $R_1 = R_2 = R_3$) then the potential difference across each resistor is equal as well (i.e. $v_1 = v_2 = v_3$). The sum of the individual potential differences is equal to the total potential difference across the combination irrespective of equal or unequal resistors. This leads to the equation showing students why the total resistance in a series circuit is the sum of the individual resistors.

To verify that the reciprocal of the total resistance in a parallel circuit is the sum of the reciprocal of the individual resistors, the diagram shows that the potential difference (V) is the sum of all the parallel resistors. However the total current (I) is "split" at the branches leading to the various resistors: i_1 passing through R_1, i_2 passing through R_2 and i_3 passing through R_3. If all resistors have the same ohmic value, then the value of current passing through each resistor is the same (i.e. $i_1 = i_2 = i_3$). If each resistor is different then the value of the current through each resistor is different. The sum of all currents (i_1, i_2 and i_3), whether it passes through equal resistors or not, is equal to the total current in the circuit. Using Ohm's Law and a constant potential difference in the circuit and across the resistors leads to reciprocal of equivalent resistance equaling the sum of reciprocals of the individual resistors.

The design of the *Resistors Worked Examples* section is based on the misconceptions students have with potential difference, current and resistance in simple circuits as identified by research (Carlton, 1980; Cohen et al, 1983; Fredett & Lochhead, 1984). Examples in this section also deal with the calculation of equivalent resistance by means of resolving parallel and series combination circuits (McDermott & Shaffer, 1992). There are four questions in the *Try These Yourself* section, each question dealing with one of the misconceptions listed above. The question-two series (question 2a to 2d) is based on the same circuit arrangement (shown in Figure 5.10 below). By using the same circuit in this series, the program develops a framework that discusses the calculation of the equivalent resistance in a circuit, the potential difference across individual resistors and across the whole circuit and the current passing through each of the resistors in parallel. The method of using the same circuit arrangement proved useful in reinforcing the students understanding of these concepts and showed them how various properties of a circuit can be tested at once.

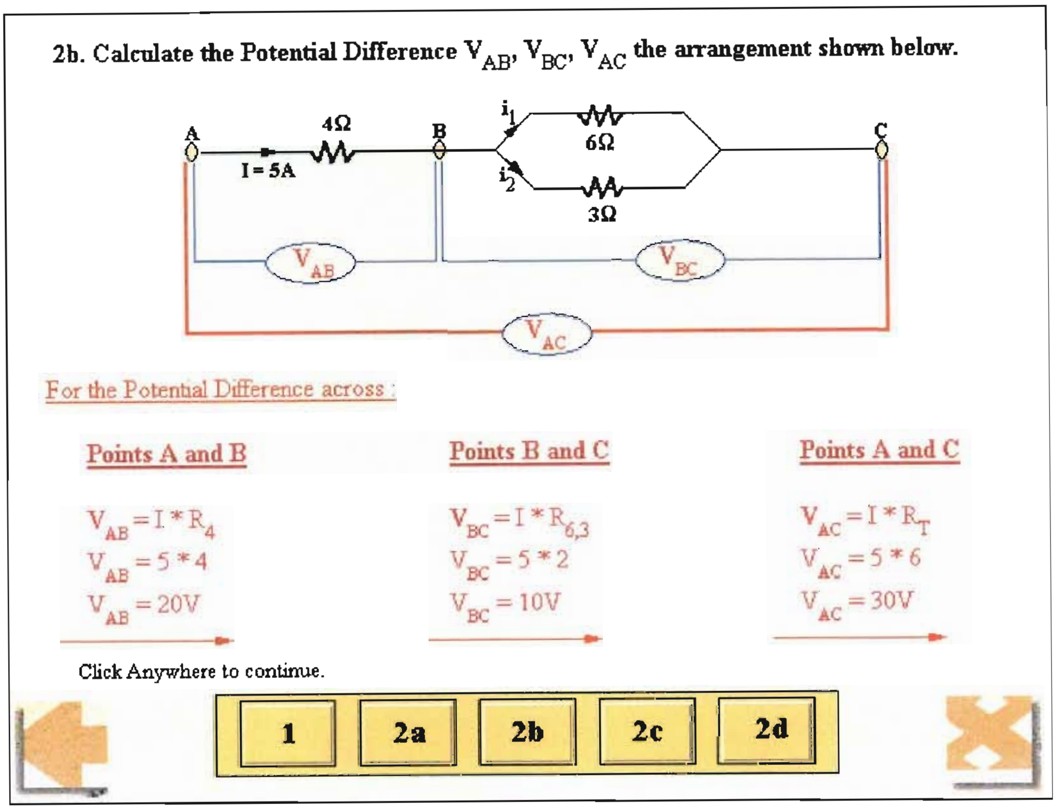


Figure 5.10: Worked Example using the same circuit to calculate potential difference

To give students practice in answering resistor-based questions and to provide them with an indication of their understanding, the *Try These Yourself* section (Figure 5.11) has a database of randomly selected questions. The database contains questions that test concepts of resistance, potential difference and current. It also includes questions dealing with electric energy and resistivity. Questions include real life scenarios such as calculating the resistance found in a telephone wire of a certain length and thickness. This creates a sense of relevance to an otherwise abstract topic and allows students to identify with what is being tested. As with other *Try These Yourself* sections, there are three attempts at each question accompanied with a hint for the first two incorrect entries. The hint for the second incorrect entry is specific to that question and highlights the physics concept which links question to solution.

The *Electricity* section of PULP was written into the programe whilst the students were using the *BMI* and *Minimum Deviation* sections, so the inclusion of the hints resulted from the comments given and the interviews conducted with students in these sections.

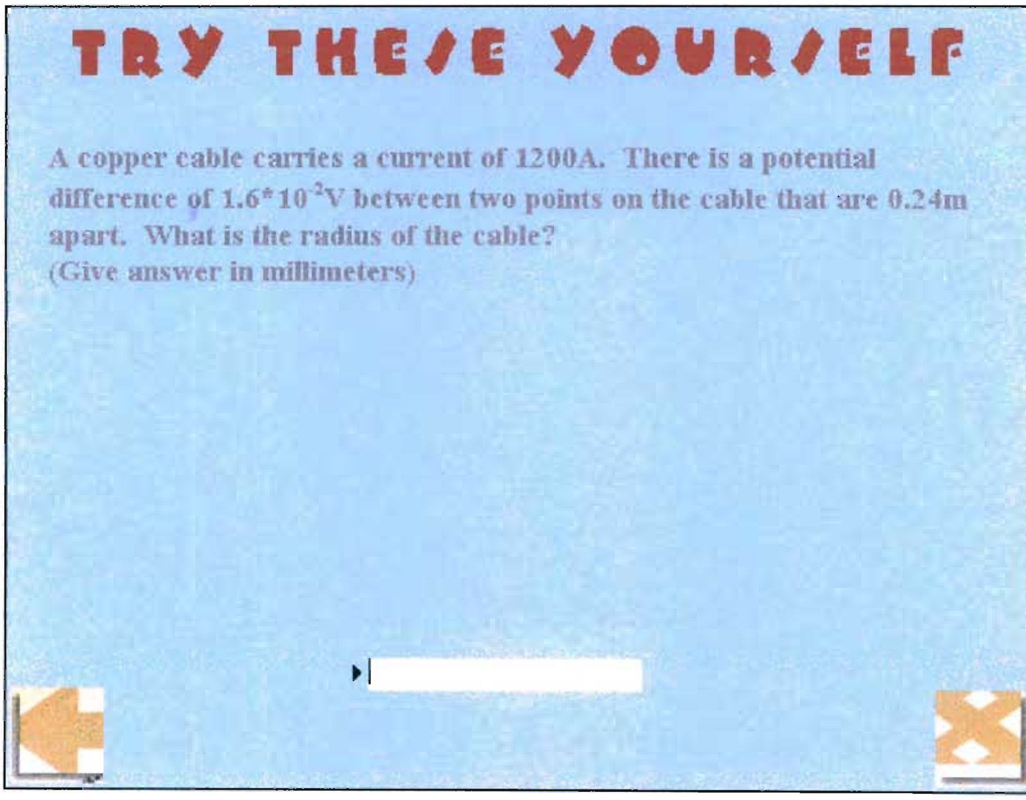


Figure 5.11: Try These Yourself question for the Resistors section of PULP

5.4.1 First assessment of students after interaction – *Resistors*

The assessment of the *Resistors* section was conducted one week after the first assessment on *Capacitors*. PULP students again had only one session in which to use the program. During that session, the instructor stressed the importance of reviewing the *Definitions* and *Worked Examples* carefully before attempting the *Try These Yourself* section, as these sections contain explanations that aid in their understanding of the parallel and series circuits in terms of potential difference, current and resistance. The question used in the first assessment of *Resistors* (Appendix 8) gives the student a written description of a circuit containing a resistor, ammeter and a battery. In order to answer this question the student must have some picture, either mental or drawn, of how the circuit is arranged and the know the properties of an ammeter with respect to its position in the circuit. The question then introduces an unknown resistor in parallel with the original circuit and asks the student to calculate its resistance. This examines the students understanding of parallel and series circuits and, if they are capable of transferring their knowledge of the properties of potential difference and current from one circuit to another. Results of the first assessment are given in Table E4 and
Graph 5.4.

	Ohm's Law	Resistors in Parallel	p.d. across Series	Pass (%)
PULP Students (n = 25)	79	85	79	82
NON – PULP STUDENTS (n = 49)	66	85	89	86

Table E5: Summary of first assessment for resistors

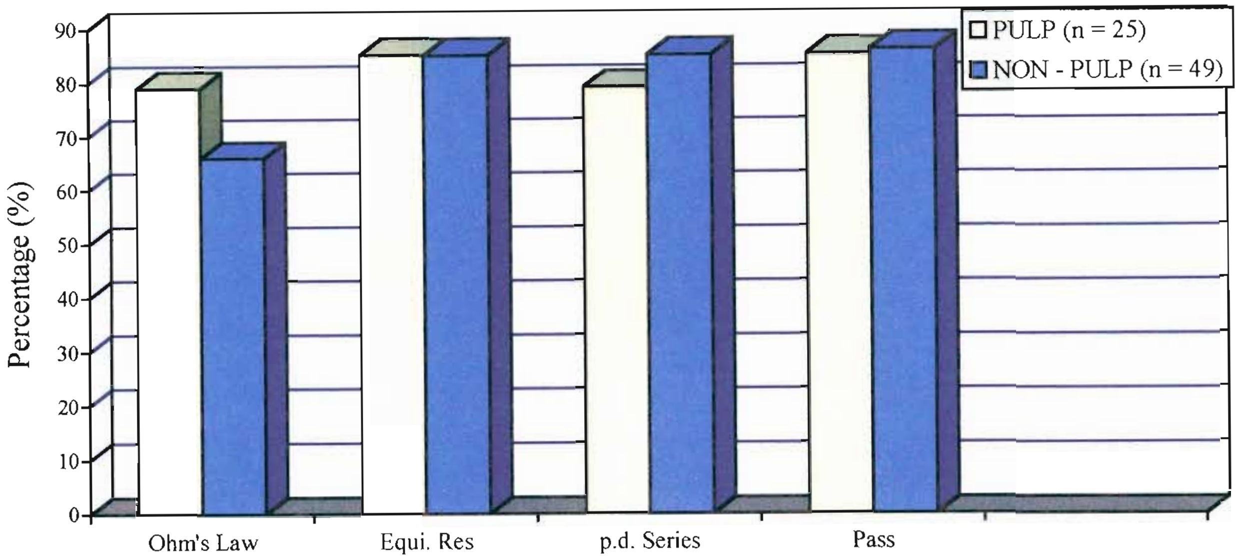


Chart E5: Summary of student performance on first assessment for resistors

5.4.1.1 Discussion of results from first assessment

An analysis of the responses shows that two students introduced a second ammeter along with the unknown resistor X. They assigned a value of 8A to the second ammeter. Since this ammeter was drawn in series with the unknown resistor, it indicted that these students had some understanding of the properties of ammeters. The inclusion of the second ammeter pointed to a misinterpretation of the question (Campbell *et al*, 2000), and although the final answer was incorrect, the method used was not. In calculating the equivalent resistance, students (5%) equated the equivalent resistance, instead of its reciprocal, with the reciprocal of the individual resistors. As the results show, most of the students were able to solve the problem. Those, apart from the two mentioned above, who answered incorrectly had erred in the mathematical calculations.

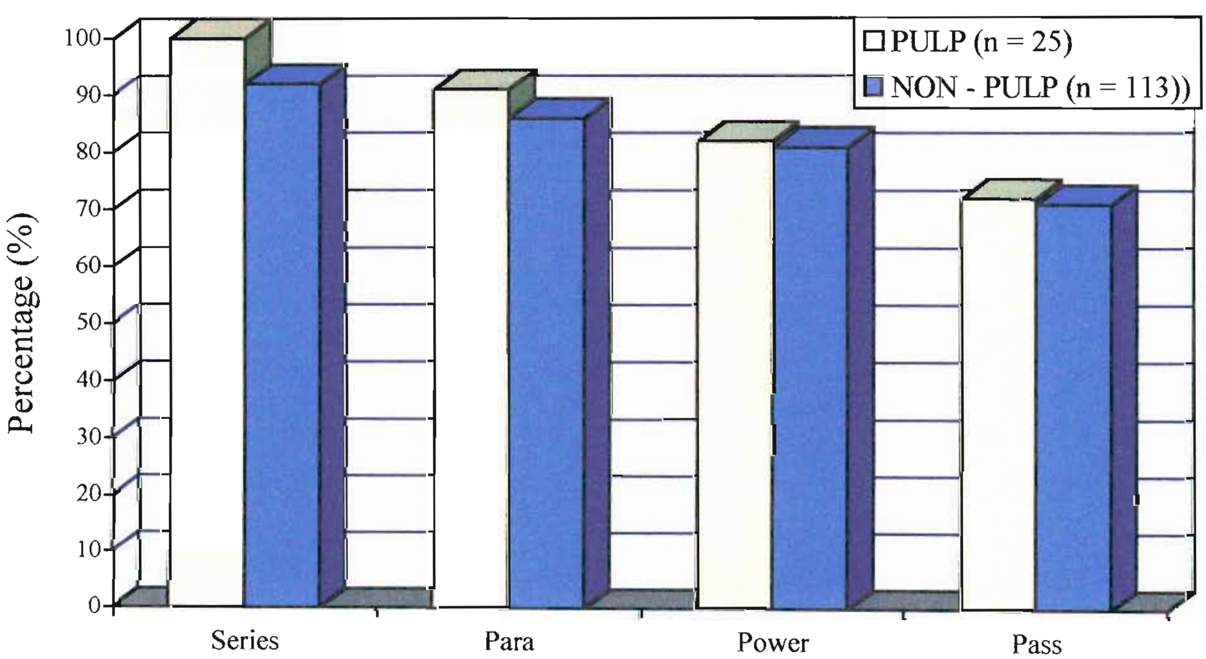
5.4.2. Second assessment of students after interaction - *Resistors*

The circuit given in this question (Appendix 9) comprises four resistors in both series and parallel combinations and requires of the student to calculate the equivalent resistance, power and cost. An analysis of the question was based on correctly calculating the equivalent resistance for the resistors in series and then using this result to find the total resistance in the circuit. In order to obtain this result, the student had to treat three resistors in parallel. Points were allocated for the calculation of the total power consumed in the circuit as well. The result of the second assessment is shown in Table E6 and Graph 5.6 below.

As the results show, all students were able to calculate the equivalent resistance for the resistors in series and a majority calculated the equivalent resistance of the entire circuit. There existed a common error in the method used amongst the 9% of students who calculated the equivalent resistance of the circuit incorrectly. For two resistors in parallel, students are taught an easy and quick method to calculate the equivalent resistance directly (Note: that this rule does not use the reciprocal of the equivalent resistance). It's commonly called the "product over sum rule" and the equivalent resistance is calculated by multiplying the magnitudes of both of the resistors and then dividing this result by the sum of the resistors. However this only applies to two (and only two!) resistors in parallel. The same rule may be used for two capacitors in series as well. The students mentioned above used the "product over sum rule" to calculate the equivalent resistance for the three resistors in parallel.

	Series	Parallel	Power	Pass (%)
PULP Students (n = 25)	100	91	82	72
NON – PULP STUDENTS (n = 113)	92	86	81	71

Table E6: Summary of student performance in second resistor assessment



Graph 5.6: Summary of student performance on second assessment

5.4.3 Summary of *Resistors*

Repeated simple resistor circuits have been used extensively to uncover many preconceptions students have that hinder their success in electricity. These circuits provide meaningful frameworks in which to test the concepts of resistance, current and potential difference. By avoiding the clutter of many electric components, students home in on the properties of resistance, current and potential difference (McDermott & Shaffer, 1992) which forms the foundation to their understanding of electricity. The provision of alternative methods, such as the *"product over sum rule"*, to perform calculations can be beneficial to students in reducing the tedium of mathematical operations, but, as the second assessment has shown, a sound grounding in the basic principles that apply to such methods must be included in this instruction. If this is overlooked then students may unknowing use these methods in situations were they are not applicable, such as in arrangements of three or more resistors in parallel or two capacitors in series.

What was discovered during the course of this investigation, was a similarity between the preconceptions students have with resistor circuits and those they have with capacitor circuits. Many students have difficulty in predicting the behavior of charge and potential difference in parallel, series or combination circuits and, as some students view the arrangement of each capacitor in a circuit in isolation, they state that charges of different magnitudes pass through capacitors in series. Their lack of understanding of capacitors causes them to use their prior knowledge of resistors in their solutions. This leads students summing the magnitudes of capacitors in series to get the equivalent capacitance and also summing the reciprocal magnitudes for capacitors in parallel to get the reciprocal of the equivalent capacitance.

Overall, students found the *Definitions* section of *Electricity* useful in their interactions with *Electrostatics*, *Capacitors* and *Resistors*. The inclusion of past examination questions gave credibility to the PULP program and the worked examples provided in the *Worked Examples* in all three sections reinforced the concepts discussed.

CHAPTER 6
CONCLUSION

This dissertation describes an investigation conducted on the effectiveness of a computer program to improve student understanding. For this purpose a computer program called the Physics Undergraduate Learning Programme (PULP) was specifically developed to address a range of conceptual and practical difficulties experienced by students. PULP is a research driven initiative of the physics programme at the School of Chemical and Physical Sciences at the University of Natal, Pietermaritzburg. The focus of this research was conducted in the content areas of electricity, minimum deviation of light as it passes through a triangular prism and the basic measuring instruments. The selection of these topics result from conversations with lecturers concerned with instructing the physics course at introductory level. Previous research done in these content areas served as the foundation of the program and was included in the design structure. The model used to assess the effectiveness of the program included pre-tests, interviews and post-tests. The students also wrote a series of class tests.

The interviews were conducted during the students' interaction with the program. An interview conducted before the student interacted with the program served as an indication of the preconception students held with the content areas included in the program. These interviews were analysed and used to modify the program to address these preconceptions. Interviews conducted with the student during the PULP sessions served as means to understand their reasoning. Again transcripts of these interviews were used to modify the program. Class tests were also used to identify student difficulty. Interviews were based on the responses students gave in their tests.

The iterative process of developing PULP proved beneficial as the results indicate. During the course of research the need for having a research group of experts in the fields of Physics, education research and computer programming became evident. Each has experience that, if included, would result in a very effective computer program.

APPENDIX 1 - Pamphlet used in PULP campaign to recruit first year physics students into programme

Get PULPed For Free

Enroll now at the Physics Department for the

***P**hysics **U**ndergraduate **L**earning **P**rogram*

It's **FREE!!! FREE!!! FREE!!! FREE!!! FREE!!!**

PULP is an interactive computer simulated learning program that offers dynamic animations, hundreds of examples and simple step–by–step instructions. PULP covers a wide range of Physics related subjects such as Mechanics, Optics, Basic Measuring Instruments and Thin Lens.

Don't get mad ! Get PULPed! It's FREE

Register now!!

Fill in your details at the bottom and hand it in at the PULP help desk!!!

Name: ______________________

Stud. No: ______________________

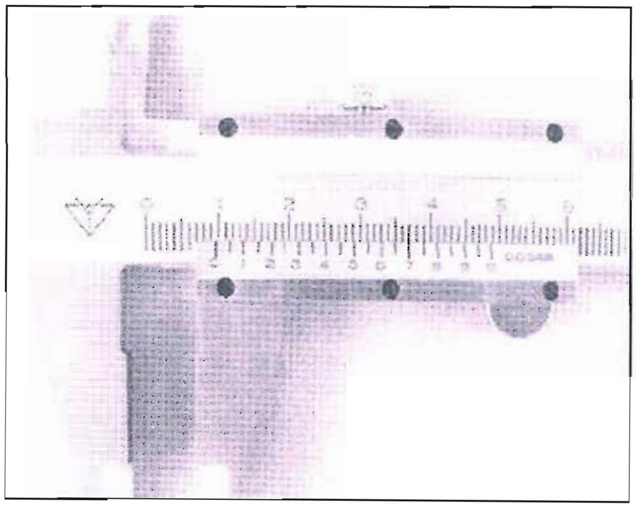
Registered Physics Course: ______________

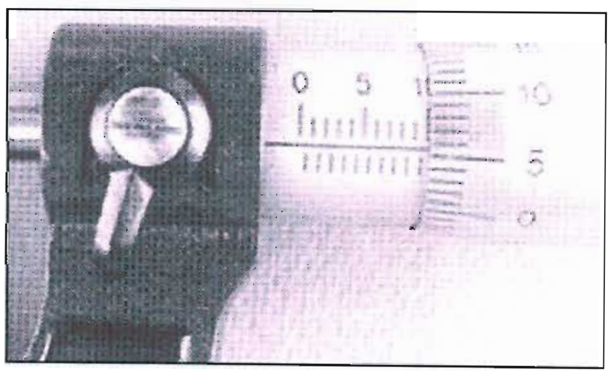
Symbol Obtained at School for

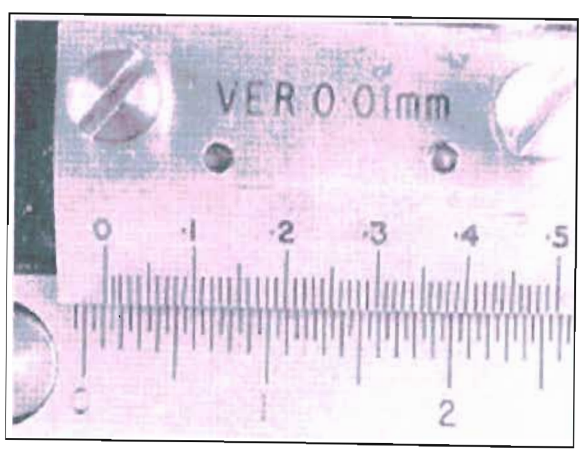
Physics: ________

Mathematics: ________

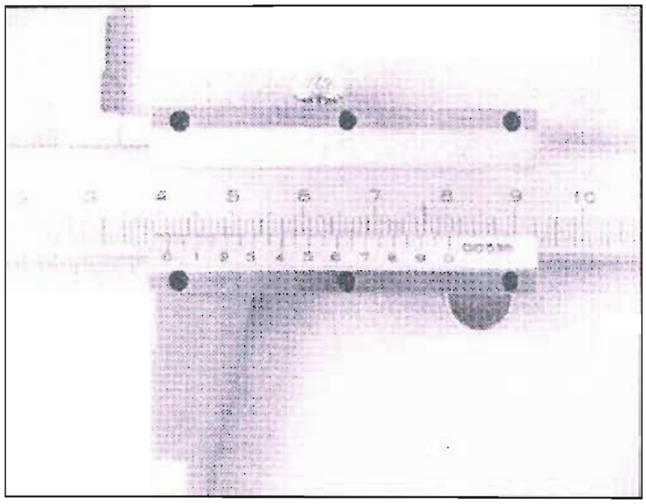
APPENDIX 2 - First test based on *Basic Measuring Instruments*. The images below show the vernier calipers, micrometer and traveling microscope.

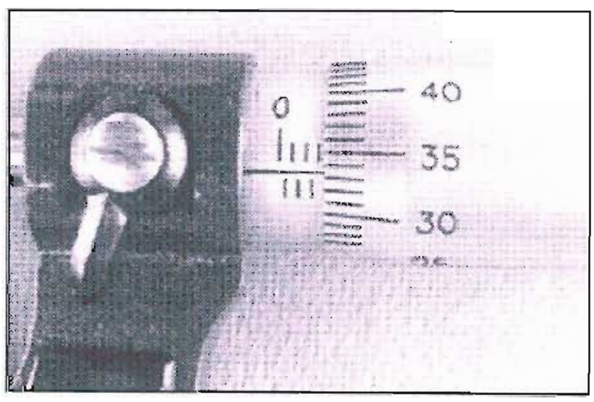


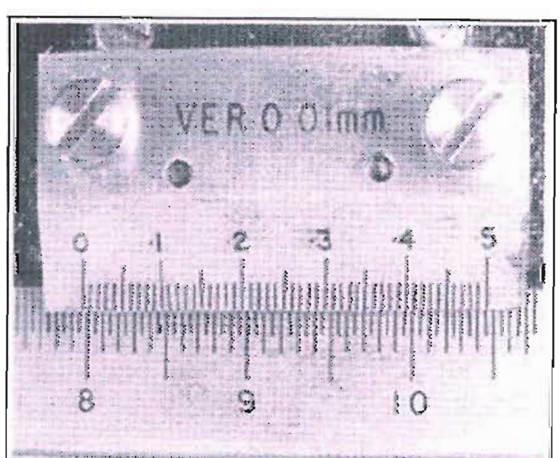




APPENDIX 3 – Second test based on *Basic Measuring Insturments*. Images below the vernier calipers, micrometer screw gauge, and the traveling microscope.







APPENDIX 4 – First assessment based on the *Minimum Deviation* section of PULP

A light ray travels through an equilateral triangular prism of refractive index 1.47. The angle of emergence is **30°**. Calculate the angle of incidence at the first surface and the angle of deviation.

APPENDIX 5 – Second assessment based on the *Minimum Deviation* section of PULP

A light ray travels through a triangular prism at minmum deviation. The angle of incidence at the first face surface is **40°** and the refracting angle of the prism is **50°**. Calculate the refractive index (n) of the triangular prism.

APPENDIX 6 – First assessment the *Electrostatics* section of PULP

PHYSICS UNDERGRADUATE LEARNING PROGRAM

PRE – TEST: ELECTROSTATICS

Question 1:

Define Coulomb's Law.

Question 2:

Using Coulomb's Law, derive the S.I units for the proportionality constant k.

Question 3:

Calculate the ratio of the Electric Force to the Gravitational Force between an electron ($m_e = 9.1 * 10^{-37}$ kg) and a proton ($m_p = 1.67 * 10^{-27}$ kg) at a separation of 1.0m

You are reminded of the following useful constants:

$q = 1.6 \times 10^{-19} C$

$G = 6.670 \times 10^{-11} Nm^2 kg^{-2}$

$k = 9.0 \times 10$ *units*

APPENDIX 7 – First assessment of students' understanding of capacitors using the *Capacitors* section of the program

PHYSICS UNDERGRADUATE LEARNING PROGRAM

PRE – TEST: CAPACITORS

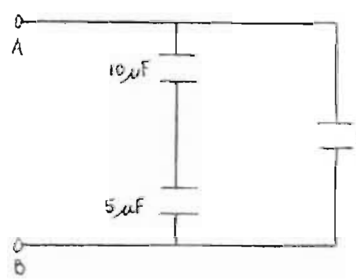
NAME: ______________________

STUDENT NUMBER: ______________________

Are you a PULP Volunteer (Circle Response): Yes / No

If Yes, which day are you registered for: ______________

Question 1



A potential difference of 100V is applied between points A and B in the circuit depicted above.

(1) Find the capacitance between points A and B.

(2) Find the charge on each capacitor.

APPENDIX 8 – First assessment of student understanding based on the *Resistors* section of the program

PHYSICS UNDERGRADUATE LEARNING PROGRAM

PRE – TEST: RESISTORS

NAME: ____________________________

STUDENT NUMBER: ______________________________

Are you a PULP Volunteer (Circle Response): Yes / No

If Yes, which day are you registered for: ____________________

Question 1

A 3Ω resistor, an ammeter and a battery are connected in series, and the ammeter reads 5A. When an unknown resistor **X** is connected in parallel across the 3Ω resistor the ammeter reads 8A. Assuming the ammeter and battery to have negligible resistance, calculate **X**.

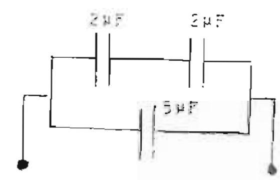
APPENDIX 9 – Second assessment of resistors, capacitors and electrostatics given by independent source and used to determine whether PULP had any improvement on the results of first year physics students.

Calculate the magnitude of the electric field at a distance of 50 cm from an isolated point charge of 20 μC, in air.

....

....

Calculate the single equivalent capacitance of the arrangement shown opposite.



....

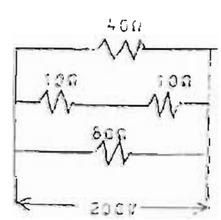
....

For the arrangement shown opposite calculate

(i) the total resistance across the 200 V supply

(ii) the total power consumed

(iii) the cost of leaving the arrangement switched on for a full week if electricity costs 15 c per 'unit'.

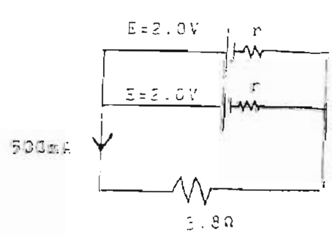


(a) Define electromotive force of a cell

(b) Two identical cells each of E.M.F. 2.0 V and connected in parallel, deliver a current of 500 mA to a 3.8 Ω resistor. (See diagram) Calculate:

(i) the effective internal resistance (r') of the arrangement of cells

(ii) the internal resistance r of each one.



APPENDIX 10 – Sample code of *Basic Measuring Instruments*.

```
Movable := 0

-- Refractive Index of Air and Perspex respectively
n1 := 1.00
n2 :=1.49

A := 60*(Pi/180)
theta1 := (90 - Round(PathPosition@"Triangle Perspex Light2")) * (Pi/180)
theta2 := ASIN ((n1/n2)*SIN(theta1))
theta3 := A - theta2
theta4 := ASIN ((n2/n1) * SIN(theta3))
D := theta1 + theta4 - A
x := 217
y :=  204          -- fixed point at center of circle

x0 := (DisplayX@"Triangle Perspex Light2")
y0 := (DisplayY@"Triangle Perspex Light2")        -- co-ordinates of light source

x1 := 217 + ( 121 * (SQRT(3)/2) * COS(theta2) / COS (theta3) )
y1 := 204 -  ( 121 * (SQRT(3)/2) * SIN(theta2) / COS (theta3)  )     -- end point of refracted ray

x2 := 200 * (217 - x0) / SQRT( ( 217 - x0 )**2 + (204-y0)**2 ) + 217
y2 := 200 * (204 - y0) / SQRT( ( 217 - x0 )**2 + (204-y0)**2 ) + 204  -- end point of unrefracted
ray

if theta4 < (Pi/2) then

    x3  :=  x1 + 150 * COS (theta4 - (Pi/3))
    y3  :=  y1 + 150 * SIN (theta4 - (Pi/3))        -- end point of emergent ray

    color := RGB(255, 0, 0)
```

```
    SetFrame(2,color)
    Line (1,x1,y1,x3,y3) --  emergent ray

   x4 := x1 + 120 / (SQRT (1+ (420/242)**2))
   y4 := y1 - (420/242) * (x4-x1)                -- end point of refracted normal

   x7 := x1 + (x1-x4) * (120 / SQRT( (x1-x4)**2 + (y1-y4)**2))
   y7 := y1 + (y1-y4) * (120 / SQRT( (x1-x4)**2 + (y1-y4)**2))     -- end point of projected
refracted normal

   color := RGB(0,200,0)
   SetFrame(2,color)
   Line (1,157,204,277,204) -- incident ray normal
   Line(1,x1,y1,x4,y4)        -- refracted ray normal
   Line(1, x1, y1, x7, y7)    -- projected refracted ray normal

   x5 := x1 + (x1 - x3) * 120 / SQRT( (x1 - x3)**2 + (y1- y3)**2  )
   y5 := y1 + (y1 - y3) * 120 / SQRT( (x1 - x3)**2 + (y1- y3)**2  )     --end point of refracted
ray projected

   color :=RGB (145,167,217)
   SetFrame(2,color)
   Line (1,x1, y1, x5, y5)       --projected refracted ray
end if

color := RGB(255, 0, 0)
SetFrame(2,color)
   Line(1, x0, y0, x, y)  -- incident ray
   Line(1, x, y, x1, y1)  -- refracted ray

x6 := x1 + 75 * COS (2*Pi/3 - theta3)
y6 := y1 +75 * SIN  (2*Pi/3 - theta3)        -- end point of reflected ray
color := RGB(175,150,44)
```

```
SetFrame (2,color)
Line (1, x1, y1, x6, y6)  -- reflected ray

color := RGB(0,0,255)
SetFrame (2,color)
Line(1, x, y, x2, y2)  -- unrefracted ray (in blue)

theta1a := ABS(Round(theta1*180/Pi))
theta2a := ABS(Round(theta2*180/Pi))
theta3a := ABS(Round(theta3*180/Pi))
theta4a := ABS(Round(theta4*180/Pi))
D1a := ABS(Round(D*180/Pi))

ThetaActive:=1
```

BIBLIOGRAPHY

Albers, C., Lubben, F., Rollnick, M., Bantom, W., Bapoo, A., Ferrer, P., Fikizolo, S., & Naidoo, D. (2002). The validity of experimental measurements in phyiscs: the understanding of Open Supported Learning students. Proceedings on The 10th Annual Conference of the South African Association for Research in Mathematics, Science and Technology Education, III2 – III3.

Allie, S., Buffler, A., Lubben, F., & Campbell, B. (2002). Constructing a research-based framework for a first year physics laboratory curriculum. Proceedings on The 10th Annual Conference of the South African Association for Research in Mathematics, Science and Technology Education, III4 – III5.

American Association of Physics Teachers. (2002). Goals of the introductory Physics Laboratory.
Received: 06/06/02.
Available online at:
http://www.aapt.org/aaptgeneral/goal.html

Bason, F. (1990). The computer as a teaching aid in physics: A case study on optics and wave theory. In Redish, E.F. and Risley, J.S. (Eds.), *Proceedings on The Conference on Computers in Physic Instruction* (pp. 127-128). Redwood City, CA: Addison-Wesley.

Beicher, R.J., DeMarco, M.J., Ettestad, D.J., & Gleason, E. (1990). VideoGraph: A new way to study kinematics. In Redish, E.F. and Risley, J.S. (Eds.), *Proceedings on The Conference on Computers in Physic Instruction* (pp. 244-245). Redwood City, CA: Addison-Wesley.

Borghi, L., de Ambrosis, A., & Massara, C.I. (1987). Computer simulation and laboratory work in the teaching of mechanics. *Phys. Educ., 22*, 117-121.

Bork, A. (1986). Pedagogical development of computer-based learning material. In Harold Weinstock and Alfred Bork (Ed.), *Designing computer-based learning materials.*(pp. 107-123). Berlin-Heidelberg.

Bransford, J.D., Brown, A.L., & Cocking, R.R., (Eds.) How People Learn: Brain, Mind, Experience and Science.
Received: 05/24/02.
http://www.nap.edu

Buffler, A., Allie, S., Lubben, F., & Campbell, B. (2001). The development of first year physics students' ideas about measurements in terms of point and set paradigms. *Int. J. Sci. Edu.*, 1 – 20.

Campbell, B., Kaunda, L., Allie, S., Buffler, A., & Lubben, F. (2000). The communication of laboratory investigations by university enterants. *J. Res. Sci. Teach.*, *37*, 839 – 835.

Carlton, K. (1999). Teaching electric current and electric potential. Phys. Educ., *34*, 341 – 345.

Chabay, R.W., & Sherwood, B.A. (1992). A Practical Guide for the Creation of Educational Software. In Larkin, J.H. and Chabay, R.W. (Eds.), *Computer-Assisted Instruction and Intelligent Tutoring Systems: Shared Goals and Complementary Approaches* (pp 151-186). Hillside, New Jersey: Lawrence Erlbaum.

Chakravarti, S., & Siegel, P.B. (2001). Visualizing the thin-lens formula. *The Physics Teacher*, *39*, 342-343.

Cohen, R., Eylon, B., & Ganiel, U. (1983). Potential difference and current in simple electric circuits: A study of students' concepts. *Am. J. Phys.*, *51*, 407 – 412.

Disessa, A.A. (1987). The third revolution in computers and education. *J. Res. Sci. Teach.*, 24, 343-367.

Duggan, S., Johnston, P., & Gott, R. (1996). A critical point in investigative work: defining variables. *J. Res. Sci. Teach.*, 35, 461 – 474.

Duit, R. and von Rhoneck, C. Learning and understanding key concepts of electricity.

Erstad, O. (1990). Multimedia in educational settings – prospects for learning.
Received: 08/23/02.
Available online at:
http://www.intermedia.uio.no/ktk/notater/notat4.html

Ferguson-Heller, M.G.M., & de Jong, T. (1987). On the quality of knowledge in the field of electricity and magnetism. *Am. J. Phys.*, *55*, 492 – 497.

Feynman, R.P. (1964). *The Feynman Lectures on Physics.* Addison-Wesley, Reading, MA.

Fredett, N., & Lochhead, J. (1980). Student conceptions of simple circuits. *Phys. Teach.*, 194 – 199.

Fuller, R.G. (1986). Resource letter CPE-1: Computers in physics education. *Am. J. Phys., 54*, 782-786.

Goldberg, F., & Bendall, S. (1995). Making the invisible visible: A teaching/learning environment that builds a new view of the teacher. *Am. J. Phys.*, 63, 978-989.

Goldberg, F.M., & McDermott, L.C. (1987). An investigation of student understanding of the image formed by a converging lens or concave mirror. *Am.J.Phys.*, *55*, 108-119.

Grayson, D.J. (1996). Conceptual substitution: A strategy for promoting conceptual change. In Treagust, D.F., Duit, R. and Fraser, B.J., (Eds.), *Improving Teaching and Learning in Science and Mathematics*. (pp. 152-161). New York: Teachers College Press.

Guesne, E. (1995). Light. In R. Driver, E. Guesne, & A. Tiberghien. Children's ideas in science. Milton Keynes: Open University Press.

Hargis, J. (2000). The self-regulated learner advantage: learning science on the internet. *Electronic Journal of Science Education, 4.*

Hendricks, A.J. (2002). Investigating whether using the computer as a tutor could enhance 1st year Pen Tech science students conceptual understanding of electrical concepts.

Hicks, R.B. & Laue, H. (1989). A computer-assisted approach to learning physics concepts. *Am. J. Phys., 57*, 807-811.

Holmes, J.B. (1990). Electric field lines simulation lab. In Redish, E.F. and Risley, J.S. (Eds.), *Proceedings from the Conference on Computers in Physic Instruction* (pp. 132-133). Redwood City, CA: Addison-Wesley.

Kibble, B. (1999). How do you picture electricity? *Phys. Edu., 34*, 226-229.

Kirkup, L., Johnson, S., Hazel, E., Cheary, R.W., Green, D.C., Swift, P., & Holliday,W. (1998). Designing a new physics laboratory programme for first year engineering students. *Phys. Edu., 33*, 258 – 265.

Kozma, R.B. (1987). The implications of cognitive psychology for computer-based learning tools. *Educational Technology*, 20 - 25.

Long, L. (2001). Factors in media selection for quality distance education.

Maloney, D.P., O'Kuma, T.L., Hieggelke, C.J., & van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *Phys. Educ. Res., Am. J. Phys. Suppl.*, *69*, S12 – S23.

McDermott, L.C. (1993). How we teach and how students learn: A mismatch?

McDermott, L.C., & Shaffer, P.S. (1992). Research as a guide for curriculum development. An example from introductory electricity. Part 1: Investigation of student understanding. *Am. J. Phys.*, *60*, 994 – 1003.

McIldowie, E. (1998). Teaching voltage-current relationships without Ohm's Law. *Phys. Educ.*, **33**, 292 – 296.

Meltzer, D.E. and Manivannan, K. (2000). Transforming the lecture-hall environment: The fully interactive physics lecture. *Am. J. Phys.*, *70*, 639-654.

Miller, R., & King, T. (1993). Students' understanding of voltage in simple electric circuits. *Int. J. Sci. Educ.*, *15*, 339 – 349.

Mulhall, P., McKittrick, B., & Gunstone, R. (2001). A perspective on the resolution of confusion in the teaching of electricity. *Research in Science Education*, *31*, 575 – 587.

Redish, E.F. (1993). Is the computer appropriate for teaching physics? *Computers in Physics*, 7, 613.

Redish, E.F. and Steinberg, R.N. (1999). Teaching physics – figuring out what works. *Physics Today*, *January*, 24-30.

Reeves, T.C. (2000). Socially responsible educational technology research. *Educational Technology, 40, 19-28.*

Reif, F. (1986). Scientific approaches to science education. *Physics Today, November,* 48-54.

Ronen, M. and Eliahu, M. (1997). Addressing students' common difficulties in basic electricity by qualitative simulation-based activities. *New Approaches, 32*, 392 - 399.

Ruiz, M.J. (1990). Interactive optics software for the general student. In Redish, E.F. and Risley, J.S. (Eds.), *Proceedings on the Conference on Computers in Physic Instruction* (pp. 125-127). Redwood City, CA: Addison-Wesley.

Salinas, J., & Sandoval, J. (2001). Geometrical optics and visual perception. *The Physics Teacher, 39*, 420-423.

Saxena, A.B. (1992). An attempt to remove misconceptions related to electricity. *Int. J. Sci. Educ., 14*, 157 – 162.

Schwamberger, J., & Zainasheff,J. (1997). *Macromedia Authorware4 – Using Authorware.* San Fransico, CA: Macromedia.

Shaffer, P.S., & McDermott, L.C. (1992). Research as a guide for curriculum development. An example from introductory electricity. Part 2: Design of instructional strategies. *Am. J. Phys., 60*, 1003 – 1013.

Shipstone, D. (1998). Pupil's understanding of simple electrical circuits – some implications for instruction. *Phys. Educ., 23*, 92 – 96.

Sillitto, R., & MacKinnon, L.M. (2000). Going SPLAT! – Building a multimedia educational resource for physics learners. *Phys. Edu., 35*, 325-331.

Singer, D., & Ganiel, U. (1990). Software packages for high school optics. In Redish, E.F & Risley, J.S. (Eds.), *Proceedings on the Conference on Computers in Physics Instruction* (pp. 123-125). Redwood City, CA: Addison-Wesley.

Singer, D., & Ganiel, U. (1990). Software packages for high school optics. In Redish, E.F. and Risley, J.S. (Eds.), *Proceedings on the Conference on Computers in Physic Instruction,* (pp. 123-125). Redwood City, CA: Addison-Wesley.

Trumper, R., & Gelbman, M. (1997). Investigating power, work and effective values in an AC resistive circuit through microcomputer-based laboratory. *New Approaches, September*, 408-414.

van den Berg, E. (1997). Improving teaching in the laboratory: Old problems, new perspectives.
Received: 06/06/02.
Available online at:
http://projects.edte.utwente.nl/smartnet/version2/cabinet/lab_teaching.pdf

Visscher, P.B. (1990). Simulation software for advanced undergraduates: electrodynamics and quantum mechanics. In Redish, E.F. and Risley, J.S. (Eds.), *Proceedings from the Conference on Computers in Physic Instruction* (pp. 134-136). Redwood City, CA: Addison-Wesley.

Warnakulasooriya, R. and Bao, L. Preliminary studies on students' understanding of electricity and magnetism for the development of a model based diagnostic instrument.

Watkins, J. (1996). Design strategies for a research-based instruction program: Comparison of authoring packages for creating interactive simulations for teaching physics. *Computers in Physics Education*, 10, 6-7.

Watts, D.M. (1985). Student conception of light: A case study. *Phys. Edu.*, *20*, 183-187.