A Study of the Implementation of Virtual Instrumentation in University Laboratory Environments

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Declaration

I hereby certify that this material, which I know submit for assessment on the programme of study leading to the award of Master of Mechanical Engineering is entirely my own work and has not been taken from the work of others save to the extent that such work has been cited and acknowledged within the text of my own work.

Signed: Philip Smyth ID Number: 50040444

Date: 28th/Jan/08

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A Study of the Implementation of Virtual Instrumentation in University Laboratory Environments

In this work six engineering and physical science laboratory experiments were developed to enhance the learning experience for students. This was achieved by instrumenting and creating virtual instruments for these experiments. The use of virtual instrumentation is directly compared with traditional laboratory teaching techniques and pedagogical principles from which both methods have developed from are discussed. Previous work utilising Computer Based Learning (CBL) in similar projects relating to this work have been used to evaluate some of the benefits of virtual instrumentation, especially those relating to increased student interest, memory retention, understanding and ultimately performance in laboratory reports. The virtual experiments discussed in this study are redesigned versions of traditional style experiments and hence a direct comparison of newer CBL techniques to traditional style laboratories was undertaken. There was no change in concepts being between the two versions of the experiments; the only difference was in the methodology of presentation. The effectiveness of these CBL techniques was assessed by looking at the performance of students using virtual instrumentation against that of other students from the same class undertaking the traditional mode of the experiments. All students were assessed by report submission, multiple choice questions relating to their experiment and questionnaires. The results of this study were also compared to other related studies within the field of CBL.

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Chapter 1 Introduction

In this section the development of where Computer Based Learning and its use as an effective tool to be used in teaching will be presented. An overview of the methods implemented along with a detailed discussion of particular methodologies will be presented.

1.1 Computer Based Learning

Computer based learning (CBL) has it roots back in the 1960's when computers filled very large rooms and the only languages of note were FORTRAN and COBOL. Both these languages are still in use today and at the cutting edge of technology [1]. It seems fitting therefore that CBL should also be at a frontier of new teaching methods. Since the 1960's computers have increased in processing speed as quickly as they have decreased in physical size. With the advent of these faster computers came the capacity to redefine the limits of computer aided instruction. There are a large number of different methodologies using CBL and these can range from being based completely online to being based solely in a laboratory environment [2]. However all CBL resources have two main components, (i) the software component, as it is a computer based tool and (ii) the didactic component, as its purpose is to instruct. Students can be engaged in an interactive dialogue with the computer and this is one of the main reasons for using CBL, as it is interactive in a uniquely captivating manner [3]. With the use of CBL and its related pedagogies and technologies comes a reduced workload on teaching staff, a more comfortable interactive environment and the potential for students to study remotely if so desired [4]. The latter can also bring financial benefit to the institution employing it by having courses available through distance education. The laboratory or studio environments are well suited to CBL courses taught both remotely and on site. In these cases, there is some evidence to show that it leads to not only improved levels of student enjoyment but also improvement in grades [5]. The main goal of any teaching environment is to provide an attractive and effective learning environment for the student. However, in order to create this effective learning environment, there is a need to ascertain what factors contribute to it's effectiveness on students' understanding, interest levels and memory retention. Therefore effective computer aided instruction tools depend upon a fundamental understanding of the learning process and the ways in which current technology can be utilised [6].

With CBL there are several benefits not only to the students but also to the staff employing such techniques. The potential benefits of effective CBL include (i) interesting, user friendly learning environments; (ii) up to date, professional images of the subject and (iii) if the course is available online; 24 hour availability not offered by conventional means. Another reason for using CBL is that in institutions offering courses in dynamic subjects it is difficult to support students with up-to-date printed textbooks and to be at pace with industry levels of technology [7]. Coupled with this is the reality that in such an environment it is also difficult for academics to stay familiar with current industry trends. There is a need to consistently update course work so that students can be of benefit to companies once they have finished their primary degree. When lectures are supplemented with quality web based CBL resources, students tend to be more motivated about their coursework. Students find that it "fills in the gaps" left missing from lectures and textbooks by providing more detailed and up to date information on the topics covered in lectures. This online facility also benefits the instructors by having a lower cost than supplying the students with supplementary notes and handouts and is easier to maintain and update and can be more interactive. CBL also offers a potential solution to increase time efficiency alongside increasing staff to student ratios [8]. Students can benefit by availing of a learning tool which allows them the freedom to learn at their own pace. With the inclusion of video and animation clips into the software students can more easily visualise complex processes and ideas. This is especially useful when CBL is introduced in either online or on-site laboratory environments where students can see a preview model (virtual instrument or VI) of the experiment. This allows the student to not only gain a better understanding of *what* they are to do in their lab but also *why* they are doing it [4]. Such visualisations can provide a high quality representation in colour which will invoke a positive response from the student in terms of his/her interest and excitement levels [9]. There is also evidence to suggest that this type of learning can be beneficial to students with low self-esteem due to the lack of peer and tutor pressure to keep up as they have the opportunity to re-visit difficult topics without suffering any criticism [10, 11].

However there is divided opinion among instructors about the benefit of using CBL in courses. Either instructors are enthusiastic towards it or quite reluctant to use it. A criticism frequently aimed at computer aided instruction (CAI) and CBL models is that it is nothing more than an "electronic text book" [12, 13]. So in order to ensure that this is not the case, an evaluation of CBL and its benefits must be made. This evaluation involves three parts: (i) understanding the product's teaching and learning objectives and its target audience [14]; (ii) gathering evidence regarding its use and effectiveness [12]; and (iii) judgment of evidence based outcomes [15]. CBL may allow through combining the pictures, animations and videos for a deeper fundamental understanding in students. There is an increasing body of evidence to suggest that students learn more efficiently from comprehensively designed multimedia presentations than from current verbal-only instruction [8, 16-18]. This may be due to the fact that humans learn through a "dual channel" of thought which means that animations and videos are processed in the visual/pictorial channel of the brain and spoken words are processed in a separate auditory/verbal channel [8]. Also in Albert Mehrabian's (1971) book, Silent Messages, [21] he discusses how there are 27 times more connections between the brain and the eyes than between the brain and the ears. From this his belief is that about 55% of memory retention stems from the visual impact of a presentation, 38%

from the tone and only 7% actually comes from the content. Further more the question arises of whether using pictures along with text is as effective as using a computer with an animation over which a narration is played. These effects were studied in much greater detail in by Rowe and Gregor [8], who suggested that there are four main types of instruction: (i) the multimedia effect; (ii) the coherence effect; (iii) the spatial contiguity effect; and (iv) the personalisaton effect. In each of these multimedia instruction techniques there was a clear indication of more comprehensive learning and deeper understanding of the topics taught. In one particular example, there was a 116% increase in more creative solutions to a problem by a CBL group, compared with the number of solutions offered by that of a group taught by conventional methods. In each problem the information supplied to each group was the same but the medium in which it was conveyed that was different [19, 20].

There are several commercial CBL programs available however these programs have a number of limitations associated with them. These include: inflexible and unfriendly interfaces, high cost, high dependency on top end PC's and upgrading difficulties. Due to this there has been more of a tailor made approach to designing programs to suit the individual institutions needs and wants. As will be discussed in the next section, course management systems (CMS) such as Moodle and WebCT are becoming more popular as teachers are using them as a portal to allow students access their courses online 24 hours a day 7 days a week. Innovations such as this are making the learning experience more interactive and are allowing students a more flexible environment in which to develop.

However it is important to stress the CBL employed must be of a significant standard in order to facilitate supplemental studies. In a review of twelve different models for online tutoring, only one showed favorable results for CBL, one favored traditional methods, six showed no difference and the remaining two did not analyse results in great enough detail to be able to distinguish the benefits. [22].

In order to be effective it is important that CBL uses up date technology and innovates in order to maintain the levels of interest. As a resul there are many different facets of CBL employing new technology, most prevalent of which will be discussed section.

1.2 Online Learning Environments

In this section the various systems through which computer based learning is employed will be presented. These will include different types of e-learning (electronic learning) object used in teaching and learning.

1.2.1 Virtual Learning Environments

Course management systems (CMS) virtual learning environments (VLE's) are being used in third level institutions and corporate circles to coordinate online courses for students. The benefit of these systems is that they allow the administrator, who is usually the person giving the course, to include tools that facilitate online discussion, chat, personal profiles, file uploading and downloading, virtual teaming, link listing, computer usage records, polling, testing and grading [23]. These systems can be powerful tools if the students finds them appealing. This leads to the question of how to create the right online learning environment using a CMS such as WebCT, Blackboard or the open source Moodle.

Studies show that students must feel safe within the environment in which they are working, i.e. that they should feel comfortable and at ease with the functionality of the CMS [24, 25]. In order to adapt students into this environment there must be elements that are flexible to the students. The tone in which the CMS is presented must be inviting and positive to encourage learners to use the software. Other necessities included; Sharing – areas where students can not only share ideas but share frustrations and celebrations with their work, Collaboration – students can work together to a common goal which should help encourage friendships and class involvement, Goals – both individual and group in order to give students something to aim for and a sense of task completion [24]. However once these environments have been set up they must also be maintained. Gilly Salmon [25], who has published has set out five key areas which teachers should adhere to. These are:

(i) Access and motivation

(ii) Online socialisation

(iii) Informative exchange

(iv) Knowledge construction

(v) Development

(i) *Access and motivation* relates to how teachers must ensure that learners have easy interaction with the software itself and how it must be welcoming and encouraging. Salmon goes on to mention how the motivational aspect is an essential element of the system. A gentle and interesting introduction should be followed by more stimulating and challenging coursework supported by help from not only the teacher but also through FAQs (frequently asked questions), forums etc.

(ii) *Online Socialisation* is an idea to create an online community in which both students and teachers can operate. Here teachers can get an idea for the type of students that they are teaching and for ways to interest them more. Students can be given online personas which include tones, graphics and humorous aspects to get them more involved [It is interesting to note that within the larger online community several sub-communities can develop and the teacher should gear his/her methods to be inline with this.

(iii) *Information exchange* relates to the transfer not only of ideas but opinions and proper methods of procedure. Through the e-moderator students can be guided to communicate with external experts in the fields in which they are studying. A common example is having an industrial colleague log in to a discussion and students would ask questions and gain an understanding from a different perspective.

(iv) *Knowledge construction.* Here students take a larger role in their own educational process. They will suggest different methods in which they would like to learn with the teacher present as a guide to help along with any problems. This breeds creativity within the students and can help the moderator with new ways of building knowledge.

(v) *Development.* As students become more confident with the system they become more committed and creative within that environment. They have developed and are responsible for their own learning stlyes. Students at the end of the process should be able to use the experience they have gained from the discussion forums to become more critical and self reflective [25]. Vanessa Dennen's research [27] on online courses shows how even though CMS systems can be well designed initially, the course can significantly suffer if these systems are not maintained. Poor instructors tend to give little or no feedback, don't act on the same level as the students and are too authoritative, keeping too closely to the syllabus, don't allow discussion and have ultimate deadlines.

Professor Curtis Bonk of Indiana State University brought together a broad spectrum of ideas in a presentation in Trinity College Dublin at the CAPSL conference in May 2005. In this presentation, lessons learned from CBL and CMS related technologies were discussed. Bonk noted that care must be taken to develop effective learning tools and that sufficient resources need to be put in place to ensure success. Table 1.1 summarises some of the important points to consider when developing CBL resources, which has seen a large increase internationally in recent years. Figure 1.1 shows an example illustrating the rise in the use of CMS in Pretoria University over a recent five year period [28].

Provide photographs of the cipants	Face to face induction preferred
Encourage, Encourage, Encourage	Social/ contextual aspects
Agree netiquette (internet etiquette)	Don't underestimate the time
All humour does not work online	Importance of timely feedback
Set clear goals	Provide technical support

Table 1.1 Important points to consider when developing CBL resources.

With all of the research and development necessary, it is not really surprising that the majority of lecturers in third level institutions still rely on purely lecture based teaching and that a shift towards a more computer be integrated system is considered a slow process. The challenge may be in fact not getting the students interested in CMS and online help but getting institutions and lecturers interested in such technologies. It appears that once an effective example of a course is present within an institution other lecturers and hence other courses will see the benefits associated with such. In 1999 there were just a little over 1500 students in the University of Pretoria, South Africa, using WebCT. In five years that number had ballooned to over 24,000 students. That's nearly a 1600% increase in five years [29].

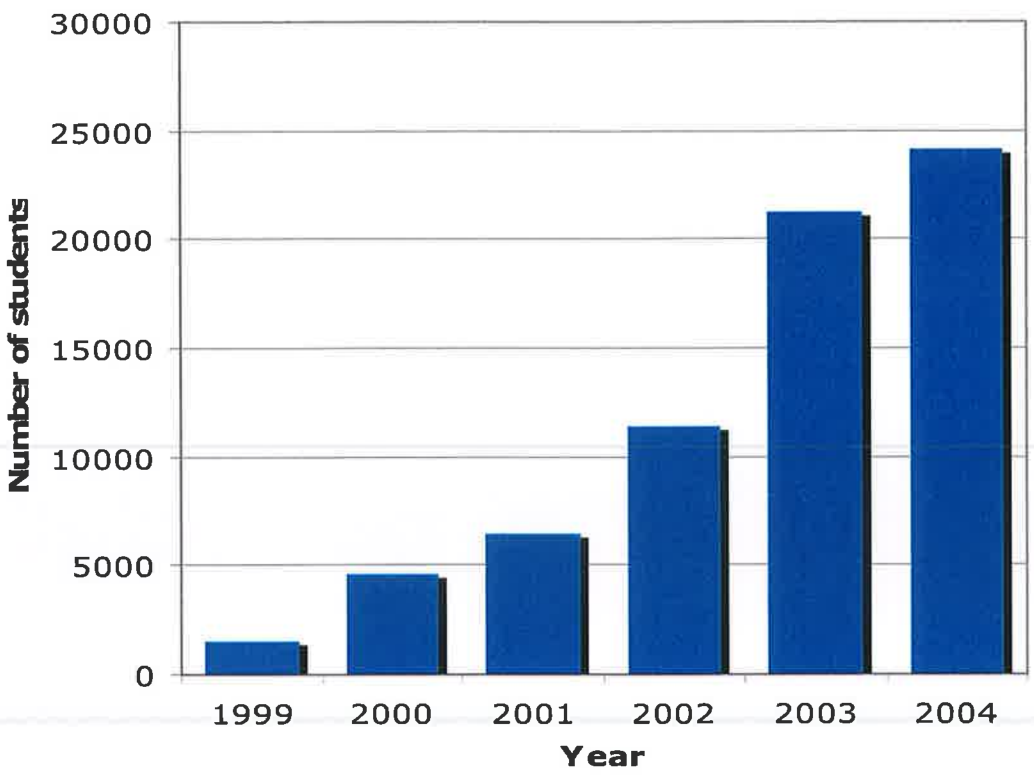

Figure 1.1 total numbers of students using WebCT in the University of Pretoria [29]

The number of distance learners using CMS is increasing along with the number of on site users. Students seem attracted to the flexibility of online courses offering freedom from constraints of time and physical access [30]. So in order to try and ensure that these learning environments are reaching a particular standard, institutions are developing standard criteria. Others are taking a more managerial outlook on CMS and seeing how these systems can free up time for lecturers and demonstrators with heavy workloads and also from a cost based issue. WebCT, Blackboard and other such environments are not free of charge and are not set up specifically for any particular course so many educators are availing of open source CMS' such as Moodle and individual systems like WebCMS [31]. The latter being used in particular at the University of New South Wales, where such a system was built by a single programmer over a period of two months working part time. This systems development, which although didn't have the complete functionality of a dedicated CMS, showed the feasibility of building and designing a specialised CMS.

However developed, these systems seem to be helping lecturers reduce workloads whilst increasing interactivity of students between themselves and between their tutors [32]. In a three year study carried out on students using the Blackboard CMS being taught a course on computer ethics in Mary Washington College, 70% found it useful, ~10% found it useful but not necessary, ~ 7% found it useful and should have used it more with only ~3% finding it not useful [32], figure 1.2. With those kinds of approval ratings coming over a three year period, tutors at MWC were satisfied (as this was not a compulsory module) that this should be used as an additional tool in teaching.

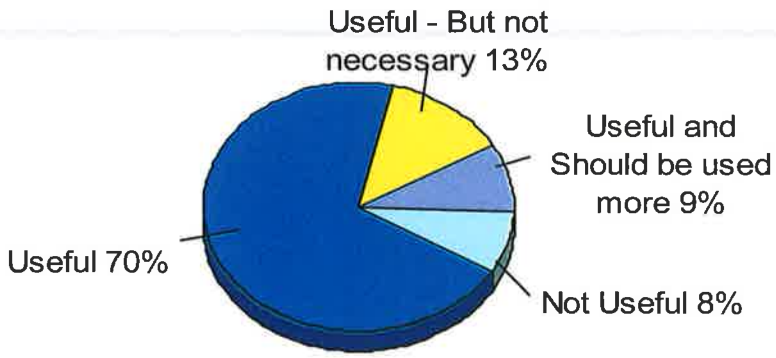

Figure 1.2 Three year study of student feedback to the used of Blackboard at Mary Washington College [32]

1.2.2 The use of a CMS in an Engineering Programme?

Usually, engineering programs are based around a system of several lecture modules which are complemented by laboratory modules. The most common model is to have several hours of lectures during the week with tutorials running simultaneously and have for an extended but singular time for laboratories. Labs can typically last for about 3 hours whilst lectures run for about 50 minutes a period. For lectures students are commonly given homework assignments to complete for the next class or to do within the tutorials. Laboratory based modules have students working with common engineering equipment and studying related phenomena. Many practicals will have pre laboratory exercise that may involve the theory or the equipment to be used and almost all will include a post laboratory studying report. Students in labs typically will work in groups due to lack of space or equipment.

CMS systems could be used before laboratories to give pre-laboratory tutorials and also question the students on their knowledge before starting the experiment. If the questions are presented through the CMS, the tutor can get instant feedback not readily available through conventional means, to see the level of understanding within the class. The tutor can then select students to be grouped together. Perhaps putting some weaker students together with stronger students can help the weaker students to benefit from others understanding. Also a CMS can be involved after the laboratory with the process getting students submitting their reports through it and hence freeing up time for the tutor. In a lecture based environment the same principals apply. By having available additional notes and online testing, students and teachers can gauge how well they have understood the material and if the student needs more time to study the material they can return to it at their convenience. This gives them a sense of control and self regulation [33]. Further general benefits of CMS are mentioned in the previous section and the reusability of the CMS allows lecturers to customise courses for different groups without having to re-write all of the material.

1.2.3 Virtual Instruments

There has always been an importance attached to having relevant effective experimentation as part of an undergraduate engineering programme. However indications are that there has been a lower emphasis placed on such experimentation in undergraduate engineering curriculums over the recent decades [34]. One reason for this in the lack of resources available to faculties for laboratory upgrade and maintenance. Third level institutions have to keep pace with industry advancements in technology; so that once students leave these institutions they have the necessary skills to compete in a competitive business environment [35]. For example, it is common practice for the results of experimental research, and industrial investigations to have been obtained automatically with the aid of a computer interface. Students must be familiar with this modern technology before leaving their programs of study. Virtual instrumentation, through the use of a Data Acquisition (DAQ) system, can recreate the equivalent of very expensive laboratory instrumentation cost effectively [4, 36]. Many institutions are embracing this technology and introducing it in their respective laboratory modules with benefits for both faculty and students. The use of virtual instrumentation and related CBL techniques also produces a reduced workload for teaching staff, a more user friendly interactive environment and allows students to study remotely if desired. With the use of visual aids included within the laboratory such as the Virtual Instrument (VI), animations and narration, students can not only gain a better understanding of *what* they are doing but *why* they are doing it [4]. Also such virtual experiments can be used to help students learn about basic programming concepts and to help them to become more accustomed with graphical based environments. Through this method of teaching engineering students are able to more easily understand the concept of the experiment, perform the data acquisition, learn about basic programming and be exposed to modern instrumentation similar to that used in industry. This familiarization with a commercial system provides them with marketable skills at graduation [48].

Recent literature has provided very interesting reports showing promising feedback regarding the introduction of virtual instruments into their respective laboratories [refs]. This positive feedback also seems to be fairly independent of the level of competency, to a certain degree, held by the instructor. Varying levels of instrument complexity and differing disciplines have, for the most part, returned similar levels of positive feedback

Virtual Instruments also have the unique ability to show students instantly how changing one particular value of a mathematical equation, for example, would impact on its end result. This can also be applied to other instances such as chemical equations and simulations. This allows students to gain a greater understanding of how the theory relates to the experiment and the effect of changing input information. Once they have gained this knowledge base they are better equipped to predict, discuss and experiment further [4, 12, 17, 33].

Such virtual instruments can also be setup to run entirely without the aid of a demonstrator in the laboratory or to be run remotely at any time. This functionality allows distance students and weaker students alike to access and re-access a particular experiment again and again. This approach allows the weaker students the opportunity for repeated access to study whilst studying at their own pace whilst distance students also get a more hands on feel to their course and this will be explored in the next section the concept they are studying.

1.2.4 Distance Education and Virtual Classrooms

Communications mediated by a computer enable students to share their opinions on topics without time or space constraints. This represents a basis for defining a distance education learning system which enables people to attend a particular course remotely. Networking services, such as Intranet/Internet, can enhance a standard learning environment with the use of different and alternative multimedia information and by promoting interactivity in the learning process. Virtual institutions (e.g. The Virtual University, www.vu.org) can be defined as representations of electronic workplaces that enable better exchange of personalized learning material and administration material and provide unique debating fields for interested students [37].

Curtis Bonk from Indiana University has stated that since the events of September 11th 2001, the use of synchronous technologies has been expanding rapidly; especially in business training environments [37]. This can be compared to third level institutions where such tools are used for expert guest interviews, student discussion, web casts, study groups, virtual classes, team meetings and even testing. Through a further development of real time technology comes the use of virtual classrooms, where students can include a personal picture of themselves and display different types of *emoticon*, similar to those found in MSN messenger, represent how they are feeling [38]. Students can also share web links and their real-time discussions can be monitored to determine of participant interaction [37].

Designing an online environment can be a difficult task at the best of times, but even if you assume that students will have a high enough bandwidth to view large files, there may be problems associated with its focus. Extreme care has to be given to every aspects of the virtual classroom so that it will become more prolific amongst the students and some basic features involved are: [38, 39].

- Encouraging self-paced learning
- Delivering teaching information and physical attributes associated with the presentation, such as gestures, to make distance students feel more involved.
- Building a competitive environment
- Presenting supplementary material
- Providing multiple communicating tools for end users

Distance education is a formal teaching system that, through the use of technology, facilitates communication between a teacher and learner situated at different locations [40]. In a virtual classroom the aim is to provide education in a manner that resembles a normal classroom. Distance education has many advantages which include, low cost, accessibility and the potential to increase the standard of education by increasing access to highly qualified teachers not available normally. However, before the benefits of distance education can be fully exploited there are still some factors that need to be addressed. These factors include the comparison with traditional distance based learning, resistance to change, recognition of qualifications obtained online, cost to students, limited interaction between students and teachers, as well as the quality of audio and video due to limited bandwidth [40]. By improving the technology employed within distance learning students can feel like they are part of a group even though they may never physically meet their classmates. The main difficulty in the use of virtual classrooms real time is a lack of bandwidth for students. This makes it quite difficult to transfer teaching and learning knowledge over the internet. One possible solution may be the introduction of video streaming technology [38]. Streamed video is a sequence of "moving images" that are sent in a compressed form over the Internet and displayed by the viewer as they are downloaded. Streaming media is streaming video with sound. With streaming video or streaming media, a student does not have to wait to download a large file before seeing the video or hearing the sound. Instead, the media is sent in a continuous stream and is played as it arrives. The user needs a player, which is a special program that can uncompress and send video data to the screen and audio data to speakers. Windows media player can be configured to be such a player with the installation of additional codec's or decompression tools. Streaming video is usually sent from prerecorded video files, but can be distributed as part of a live broadcast show. In a live broadcast, the video signal is converted into a compressed digital signal and transmitted from a special web server that is able to multicast, i.e. sending the same file to multiple users at the same time [41]. This means that a large number of students could be watching the same lecture synchronously.

Another exciting facet of distance learning is how environments that adapt to the particular student that's working in them and were there are various techniques being employed to monitor the level of students' understanding. These include online quizzes and surveys but one of the most innovative techniques being employed is the use of a video camera and software that will recognize the expression of the face of the student whether it be happy or sad. With opinion polls, online quizzes and answers to questions conscious or intentional feedback from the student - the unintentional feedback through gestures, expressions and body language that teachers in conventional classrooms are used to, all determine lecture pace and the students' understanding of coursework [40].This innovation provides a better resemblance between the traditional classroom and the online learning environment.

1.3 Recent studies related to this project

More recently published papers in educational and scientific journals have confirmed previous studies mentioned in sections 1.1, 1.2 and 1.3. The main goal of this work was to improve the learning experience for students taking the laboratory modules in DCU and to analysis the effectiveness of this enhancement. The more recently published studies bolster the premise of this study to improve the existing laboratories in DCU. Several draw attention to the many benefits of virtual instrumentation. Shepstone remarks at how new and novel ways of instruction can engage students more due to the fact that they are different from the normal methods students are used to [44]. Such novel ways are just limited to the way that computers are planned to be used as platforms for experiments rather than a standard laboratory module. By using computer rather than a traditional methodology such a change in activity captures the attention of students. Giving them real life examples to relate to allows students to more easily identify and understand the possibly abstract concepts that they are being taught. The more novel it is, the likelier it is to be remembered which will aid in students recalling other parts of their associated coursework. If students then find that they like this novel method of instruction it may inspire them to follow on and invent other inspire technologies [44, 45]. Several other groups have benefited from their implementation of CBL techniques into their laboratory setups and several others have done the same with National Instruments LabVIEW which was used in this study [46, 47, 48]. However, it is important to note that although several studies have looked at several different methods of improving their laboratories, none have tried to include all of these improvements whilst maintaining hands on approach for student interaction with the apparatus in the lab. The more senses students use to learn the theory, the more likely they are to remember it [8]. The enhanced realism of a computer simulation aids the conceptualisation process of decision making and problem solving associated with the discipline of engineering. It is noted that students find pleasure in these computer-based laboratory exercises. In general students are able to proceed at their own pace to satisfy their curiosity and use their initiative. Nevertheless the dangers of using simulation systems should be obvious to any laboratory manager. As the simulation becomes more complex, students may understand what the computer is doing, but may not be able to detect errors, in fact they may not care as long as they get their report completed and a good mark [49]. It is therefore important to ensure that CBL is constructed so that students have grounding in the hands on approach to their apparatus and use the CBL tool for what it is, a tool to enhance their learning experience not as a tool to do the learning for them.

Chapter 2 Design of Experiments

At the time of this projects inception, laboratories in Dublin City University, such as the undergraduate mechanics laboratory, were similar to the majority of those in use throughout Ireland and universities worldwide. Students in groups numbering between twenty and thirty attended laboratory classes aimed at giving them a working and practical *hands-on* understanding of principals and phenomena associated with their course of study. The laboratory manual was the primary source of information with details of instructions and explanations for the experiments to be done within an average three hour period. Lab demonstrators helped students with specific problems encountered during the lab. Once students had completed an experiment, they were then free to leave and write up a comprehensive report on their experiment which was to be handed up at the next scheduled session.

The aim of this work was to design virtual experiments for such laboratories and use them to interest the students, enable them to more easily understand the concepts being taught to them, record the data from the experiment, engage them with the topics presented and exposed them to modern instrumentation similar to that used in industry. This was done by generating Graphical User Interfaces (GUI's) and data logging from the experiments using the LabVIEW programming language.

2.1 Software used for VI development - LabVIEW

National Instrument's LabVIEW is a leading graphical development programming language with in built functionality for simulation, data acquisition, instrument control, measurement analysis and data presentation. LabVIEW is short for Laboratory Virtual Instrument Engineering Workbench. Programs written using LabVIEW are known as virtual instruments (VIs). They differ from text based programming languages such as

BASIC and FORTRAN as LabVIEW uses a graphical programming language known as G. The programmer manipulates graphical entities, called icons and wires, to construct the program. The program therefore relies on graphic symbols to describe the programmed actions. These graphical symbols are easily identifiable symbols that would be familiar to engineers and scientists alike. Pop-up dialogue boxes also describe these entities when the mouse is held over them. Figure 1 shows a screen shot from LabVIEW of the palettes that are used to pick out the icons for programming. LabVIEW also provides the user with a library of ready-made virtual instruments and functions to help programming. However one of the key features included within LabVIEW (version 7 onwards) is the new Express VIs. These allow the user to program common measurement tasks while requiring minimal wiring as the VI configuration is accomplished with dialog boxes. Examples of such common tasks would be data acquisition, signal simulation and signal analysis.

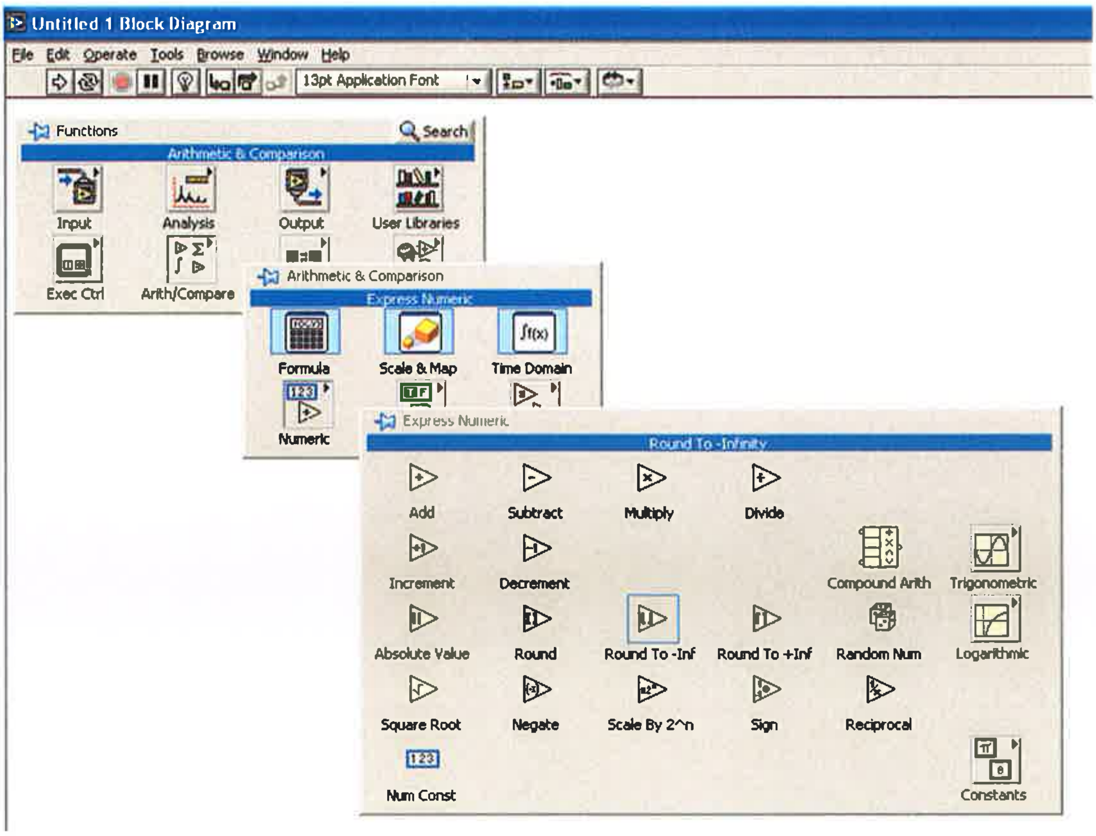

Figure 2.1 Screen shot showing an example of the

palettes used when programming.

Aside from the express VIs LabVIEW also contains application specific libraries for instrument control, data acquisition, and data analysis. LabVIEW also contains a good set of VIs for data presentation on various types of tables, charts, and graphs.

2.2 Design of Graphical User Interfaces

LabVIEW was used to design graphical user interfaces (GUIs) for each of the six experiments that were instrumented. Each of these experiments had already been employed in traditional format within existing laboratories in Dublin City University. Groups of four or five students worked together on each experiment in order to explore and verify various engineering phenomena. The main content for the new virtual instruments was taken from the same manuals used previously in the traditional format of the laboratories. A three section 'home screen' storyboard format was developed over the first year of this work and used for the virtual instruments, see figure 2.2. The GUI created in LabVIEW is known as the Front Panel. The general background to this format is described below and then in detail for each of the developed virtual instruments.

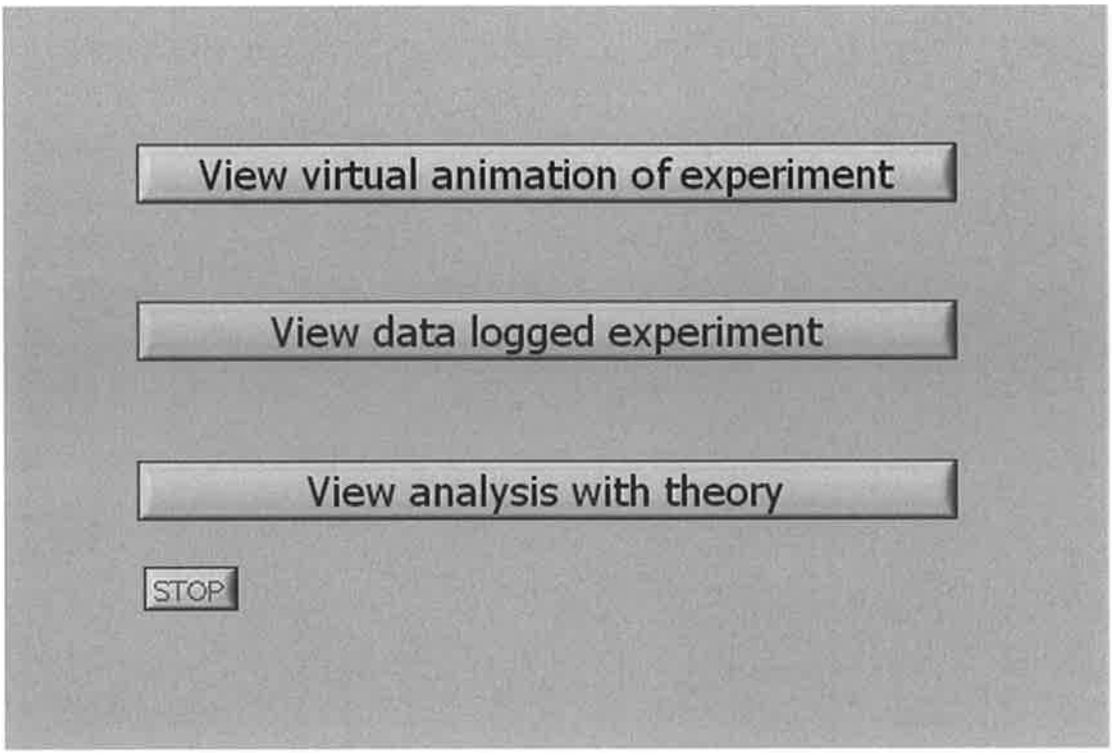

Figure 2.2 Screen shot of the Home Screen format developed.

2.3 Format of virtual instruments

2.3.1 Introduction

Each virtual experiment begins with the home screen. This screen is the start point for each experiment but also for the three sections of each experiment. Clicking the introduction section tab brings students to an animation screen of the experiment in operation. In this section the students are given an overview of the experiment to be undertaken, how it works, what is being measured and how it relates to real life situations. Previously it was common place for the laboratory demonstrator to give the students a brief introduction to the experiment but now with the aid of the virtual instrument, demonstrators are able to give the students a thorough introduction and overview of the experiment to be done. Students can listen to the demonstrator while watching the virtual version of the experiment. Through this section students are introduced to the operation and concepts of the experiment which enables them to gain a working knowledge of the apparatus.

Once the student completes the introduction section he or she clicks the 'Next Screen' button to be automatically brought back to the home screen. This system allows students to return to previous sections later on in the experiments in case they have any problems or questions. It also gives the students a sense of completion and progress during the experiment.

2.3.2 Experimental procedure and data logging

In this part of the VI students are presented with the experimental equipment, set-up and procedure to be followed. The experiment can also then be performed by the students with this section of the VI left open. The students then see the results of the experiment recorded automatically and in real time.

The use of this data logging section of the VI, allows students to capture the data via the computer. It is important to note that although the data for the experiment is recorded on the

PC during the experiment, the students still set up the apparatus manually and perform the experiment as normal. With the implementation of the VI, students are free to watch the experiment itself without worrying about counting or recording data. This allows them the time to concentrate on what is happening in front of them. Once finished with this second section, students proceed via the home screen to the final theory and calculation section.

2.3.3 Theory and calculation

In this third and final section of the virtual instrument, students are shown the theoretical background they need to analyse the data they have recorded. Students are first prompted to analyse this data, with the theory shown, on pen and paper. Once they are satisfied that they have gotten the correct answer they are allowed to enter their own figures into the equations on screen. The demonstrator then enters a password and if the student's answer matches the on screen answer then that section of the experiment is completed. If the computer does not verify their answer then the students are asked to recalculate. This forces students to examine the physical processes that have occurred during the experiment rather than just substitute values into equations and calculate answers without understanding their significance. This enables them to understand the phenomena being studied.

Students were given an answer booklet to accompany their experiment and to help with organizing their report. This includes several introductory questions at the beginning of the booklet to guide the students into the theory involved. Once the students have completed these and the demonstrator signs off that he has witnessed and questioned their answers, students are free to fill the booklet with their data. When their experiment is completed students then take a short multiple choice question test covering understanding of the concepts covered in the experiment.

These questions are set at a slightly higher level than those posed in the experiment itself and are used to gauge the students' level of understanding of the concepts being brought forward to them. The MCQ tests were originally introduced as a means of ascertaining students' levels of understanding but later proved to be a useful tool in complementing students learning once they had attempted them and therefore are now part of the experiment.

2.4 Flywheel Experiment

The first experiment to be instrumented was the moment of inertia flywheel experiment. This forms part of a first year mechanics module. Flywheels are devices that are used to store potential energy which can be released on demand to do mechanical work in the form of kinetic energy. Groups of four or five students worked together to verify and understand the concepts of moment of inertia, as well as transformation and conservation of energy. The content of this experiment, derived from the original manual, was not changed in the new VI method of instruction.

As with all of the experiments this virtual experiment was designed around the three section home screen model described above. As this was the first experiment to be developed several teething issues had to be resolved and therefore it took the longest to complete. A picture of this experimental apparatus is shown in Figure 2.3. The data logging and interface PC for the students can be seen to the left of the experimental apparatus. Figure 2.4 shows the home screen that was developed. Each of the experiments was redesigned during the summers between academic years over the initial years of this work. Feedback from the students, demonstrators and lecturers was used to perform this task. This allowed for the virtual experiment's content and delivery method to be customised for each of the labs to that which would most assist the students.

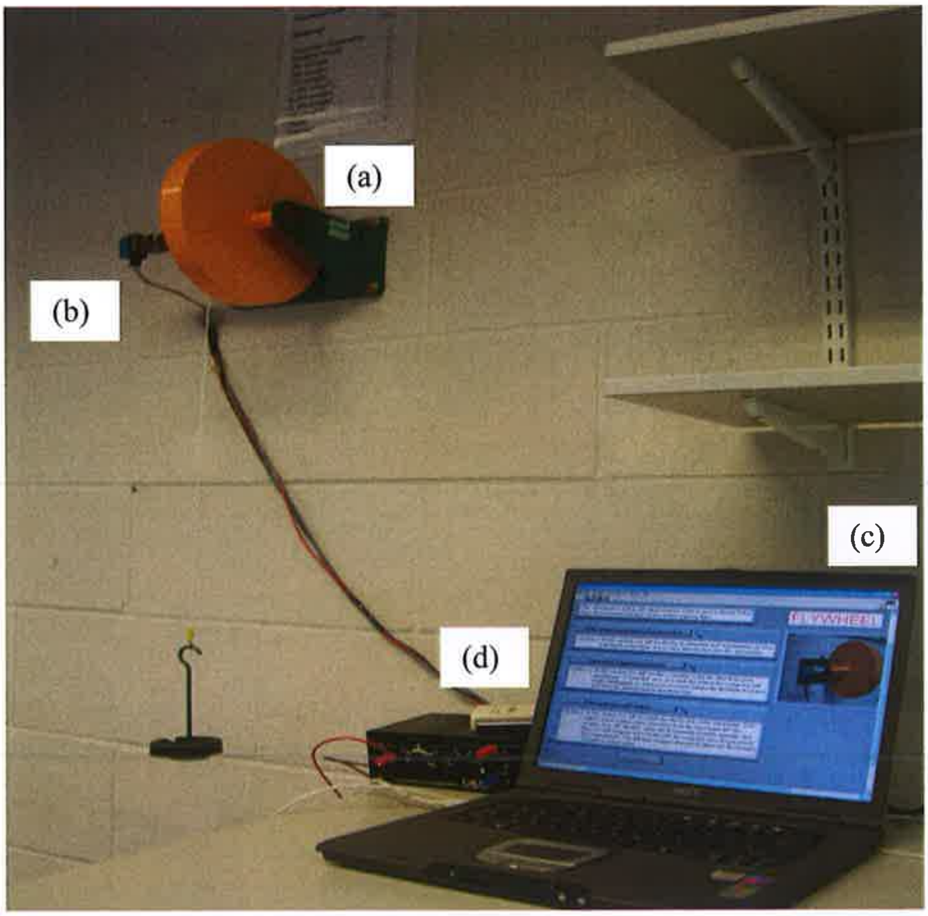

Figure 2.3 Flywheel experimental apparatus (a) flywheel apparatus, (b) rotational sensor, (c) VI, (d) USB data acquisition box

The home screen is where all the parts of the experiment are linked together for the student. The corresponding block diagram is also where all of the separate sub VI's are linked together which make up the program behind the virtual experiment. In figure 2.5 the block diagram, set within a while loop, for the home screen of the flywheel experiment is shown. This sub program repeats inside it until the conditional terminal receives a false Boolean value. When a while loop is placed on the block diagram, the corresponding stop button for this Boolean appears automatically on the block diagram and is wired to the conditional terminal. Several case structures were placed within the while loop. A case structure has one or more sub diagrams, or cases, exactly one of which executes when the structure executes. The value wired to the selector terminal determines which case executes. This value can be Boolean, string, integer, or enumerated type. In this instance the case structure is wired to a button which when clicked activated the "true" condition and ran the case structure wired to it. The block diagram case structures corresponding to sections one and two contained a single sub-VI in each and once a student completes one of these he or she can alter the selector to be brought back again to the home screen. This allowed the students to be returned to the home screen on completion of each section. Section three was programmed differently in that it has a flat sequence structure within it. In this case it consists of three sub programs, or frames, that execute sequentially. Frames in a flat sequence structure execute in order and when all data wired to the frame are available.

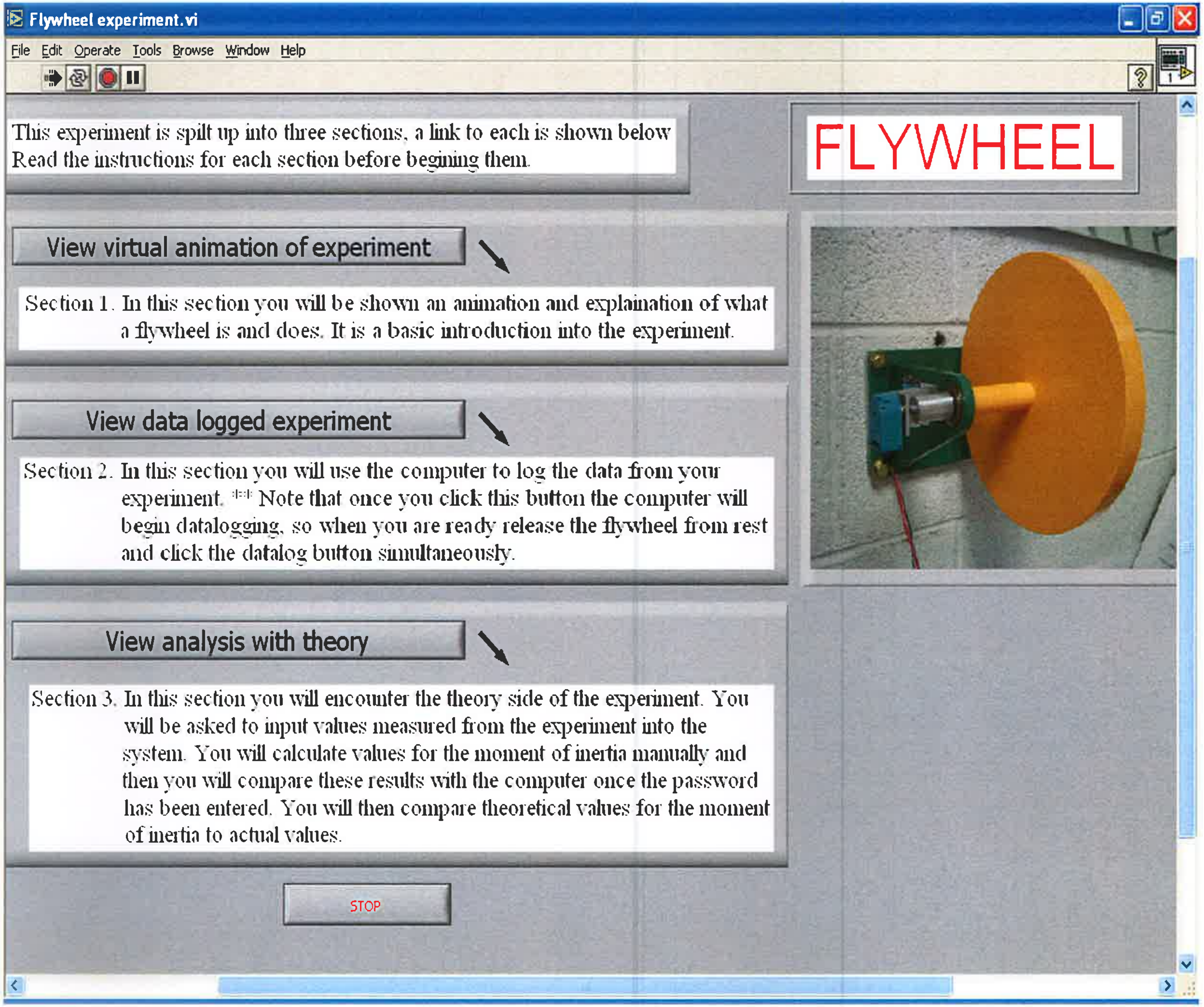

Figure 2.4 Home screen for Flywheel Experiment

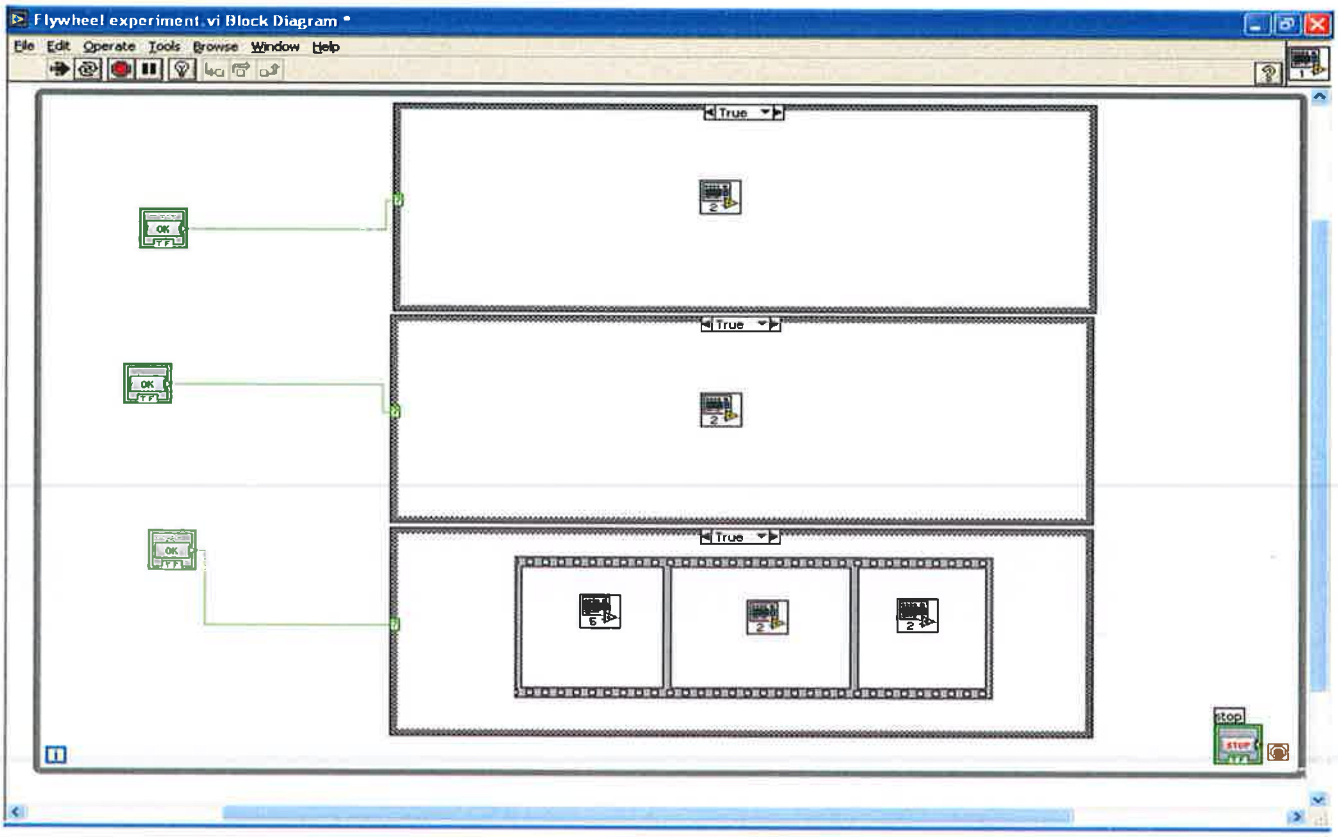

Figure 2.5 Block diagram corresponding to the Flywheel home screen

2.4.1 Flywheel introduction and theory

For this experiment the students were presented with a simple animation of the flywheel in operation. Whilst the animation was running the demonstrator explained various elements of the flywheel apparatus, the law of conservation of energy and real life applications. Explanatory text boxes were added to help the students if they wish to return to this section later on in the experiment to confirm their thoughts once the experiment had been run. Figure 2.6 shows the animation screen for the flywheel experiment.

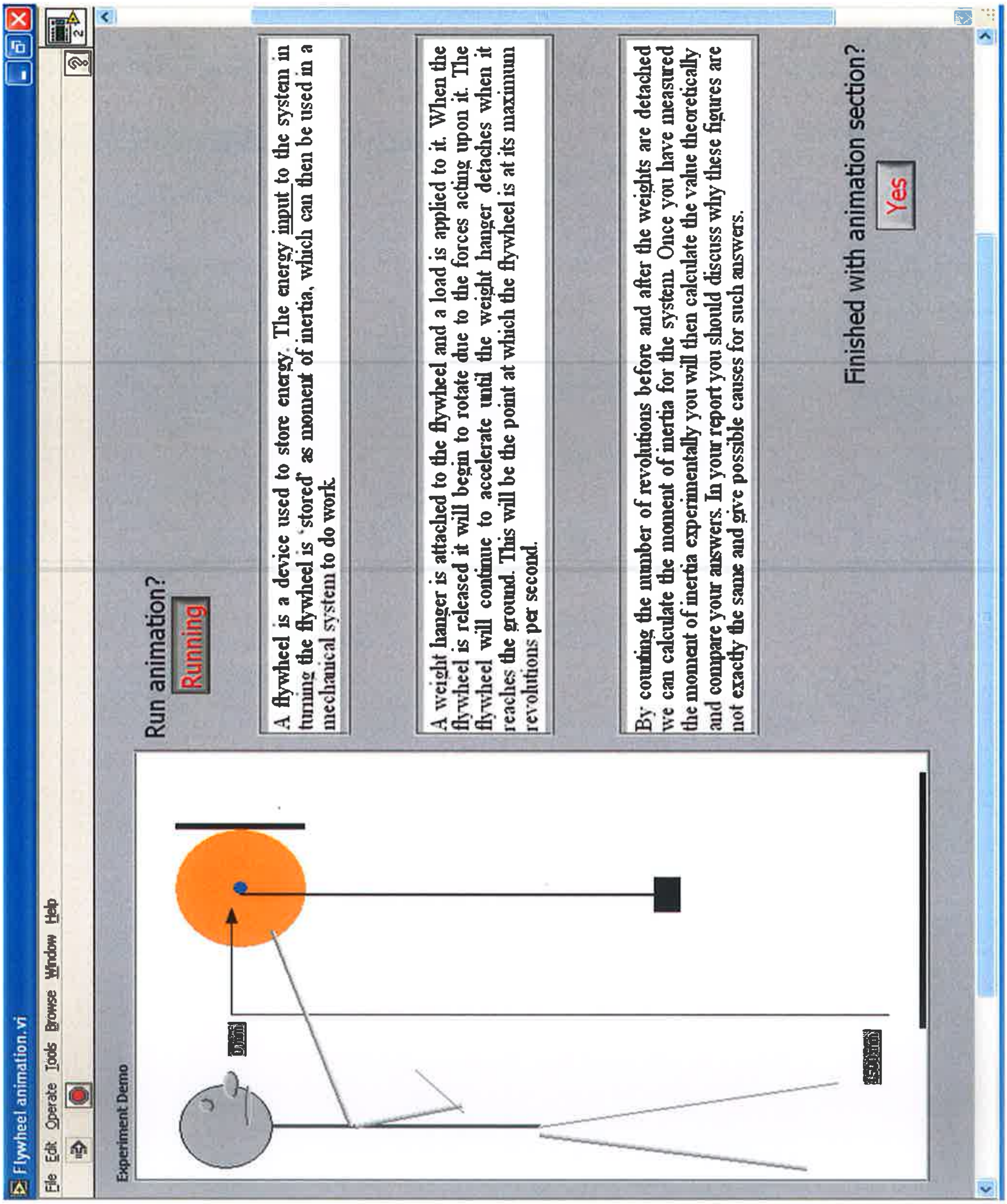

Figure 2.6 Animation screen for the Flywheel experiment

2.4.2 Flywheel experimental procedure and data logging

Section two or the data logging section was used when the students actually performed the experiment. The computer does not control any part of the apparatus, it was programmed to record the data needed to perform the calculations in the final section of the experiment. For this experiment an E-series National Instruments PCI card and data acquisition box (DAQ box) were used. A rotational sensor which is fixed to the axel of the flywheel was wired directly in to the DAQ box and was used to record the number of rotations and rotational speed of the flywheel. Specification sheets for the hardware used can be seen in Appendix D.

In figure 2.7, the data logging screen used by the students to record their data is shown. The students were presented with the same animation image as they saw during section one of the experiment. This time however the animation movement was controlled by the signal coming from the rotational sensor such that the weight was seen to drop in phase with the real life situation. The number of rotations of the flywheel was shown in the top left hand side of the screen along with a real time graphical plot of the flywheel speed versus time. This real time graphical representation allowed students to visualise what was happening in the experiment and permitted them to directly relate it to their own results. Students could easily see a sharp acceleration and gradual slow down on the flywheel as it rotates. This feature also allows the demonstrator to explain what was happening during the experiment as needed. Students found it easier to understand the concepts being taught as they could see the experiment operating in front of them and also simultaneously being animated and data logged. Results in the next chapter will highlight these benefits more clearly.

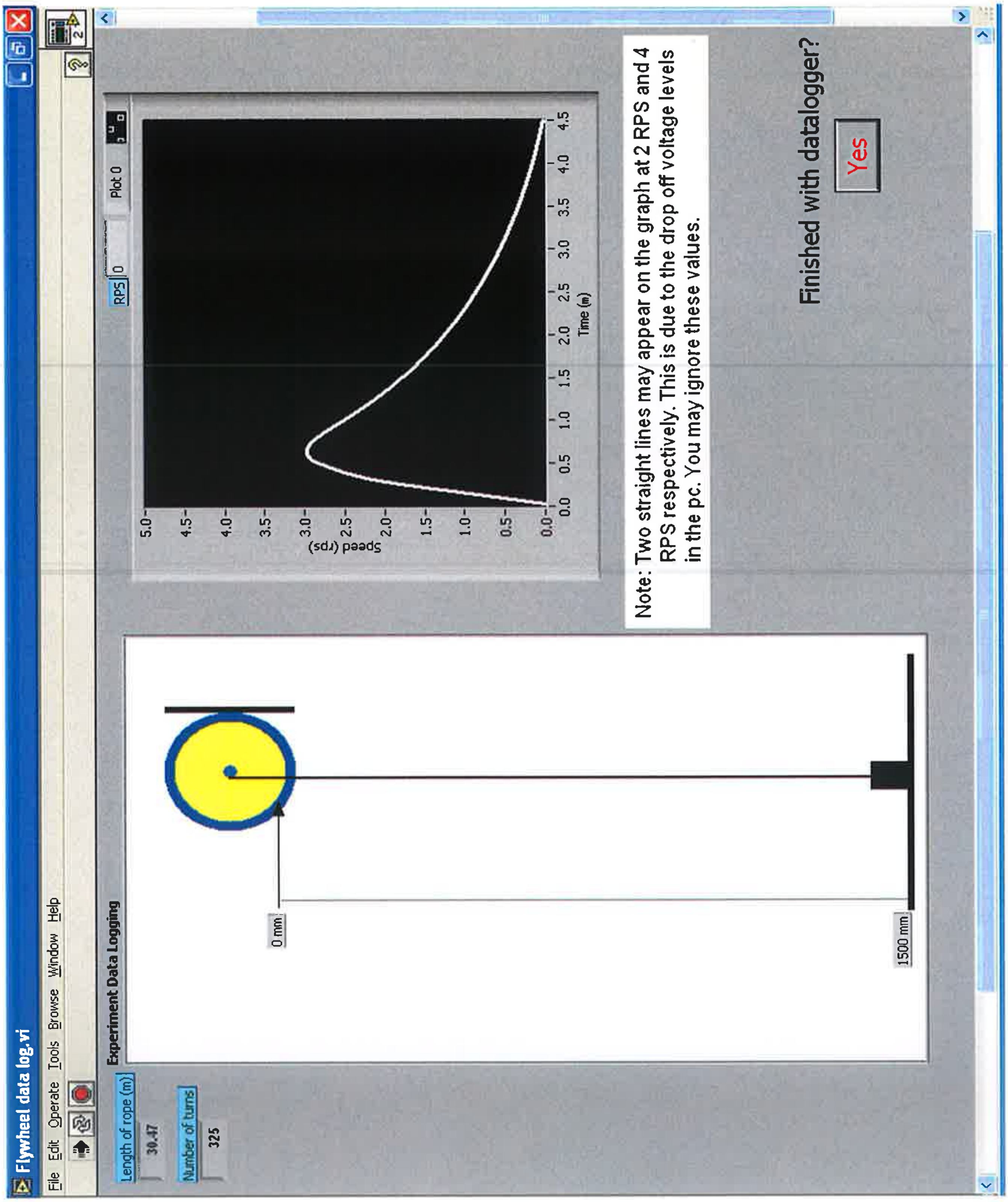

Figure 2.7 Real time data logging screen for flywheel experiment.

Students repeatedly used this section of the virtual instrument with various different weights attached to the cradle on the flywheel with each run being recorded on the PC. With this section completed they continued to the final section, again via the home screen.

2.4.3 Flywheel theory and calculation

In the final analysis and theory section of the experiment students inputted their results from section two (data logging) and attempted to calculate the frictional torque (T_f) and moment of inertia (I) of the flywheel. When using the virtually instrumented version of the flywheel it is important to note that students still carried out these calculations manually. Once the students thought they obtained the correct results, they entered the experimental parameters in to the tabs provided and the demonstrator enters a password which allowed the VI to calculate and show the correct values for both I and T_f. If the students answer was wrong they had to re-calculate their answers and try again. Once the student's answer matched the correct result, they were allowed to proceed to a final calculation screen. Figure 2.8 shows the front panel that the students were presented with and the tabs for entering data. Figure 2.9 shows the associated block diagram with the applied equations within a case structure and its password protection. This password protection was useful for laboratories for undergraduate students within their initial years but is not deemed necessary for more mature students in the later years.

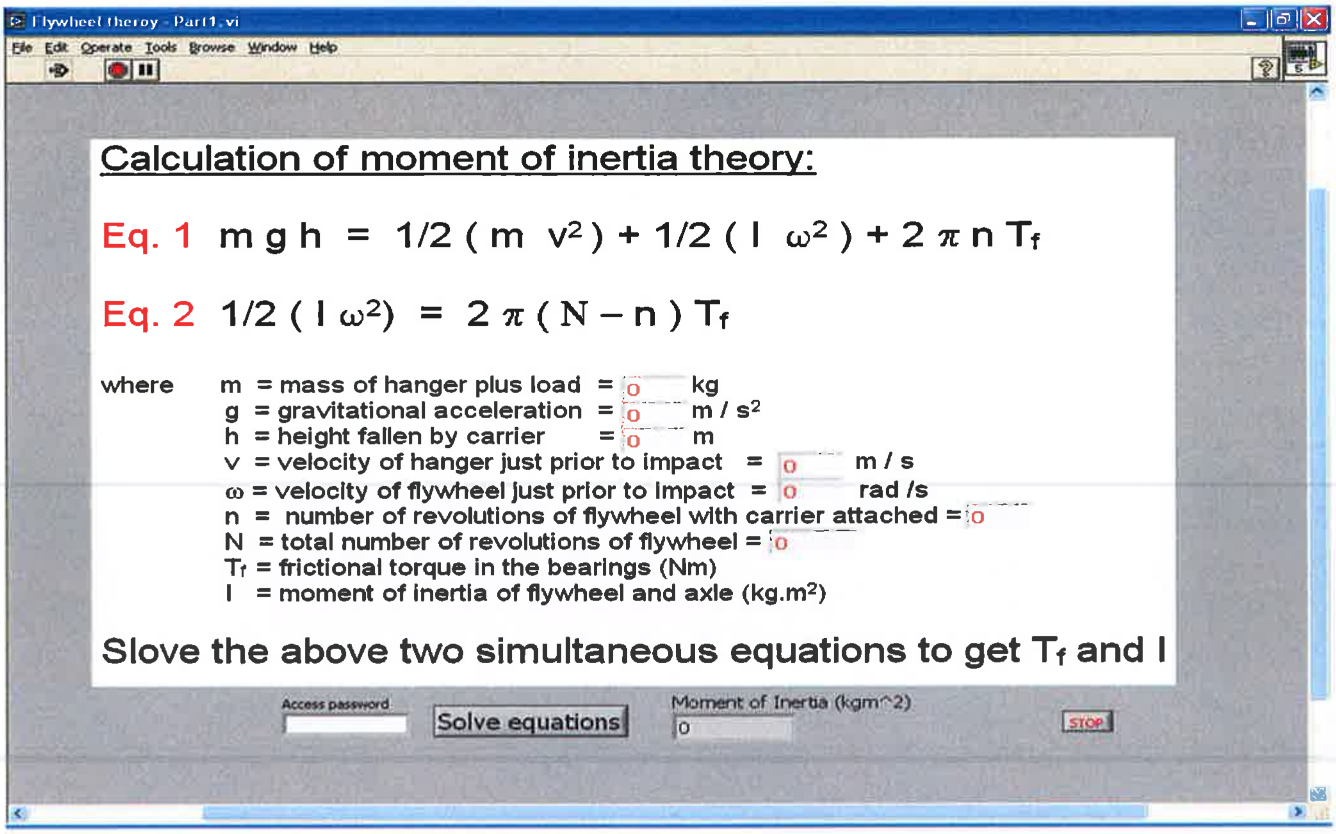

Figure 2.8 Analysis and theory section screens for the flywheel experiment

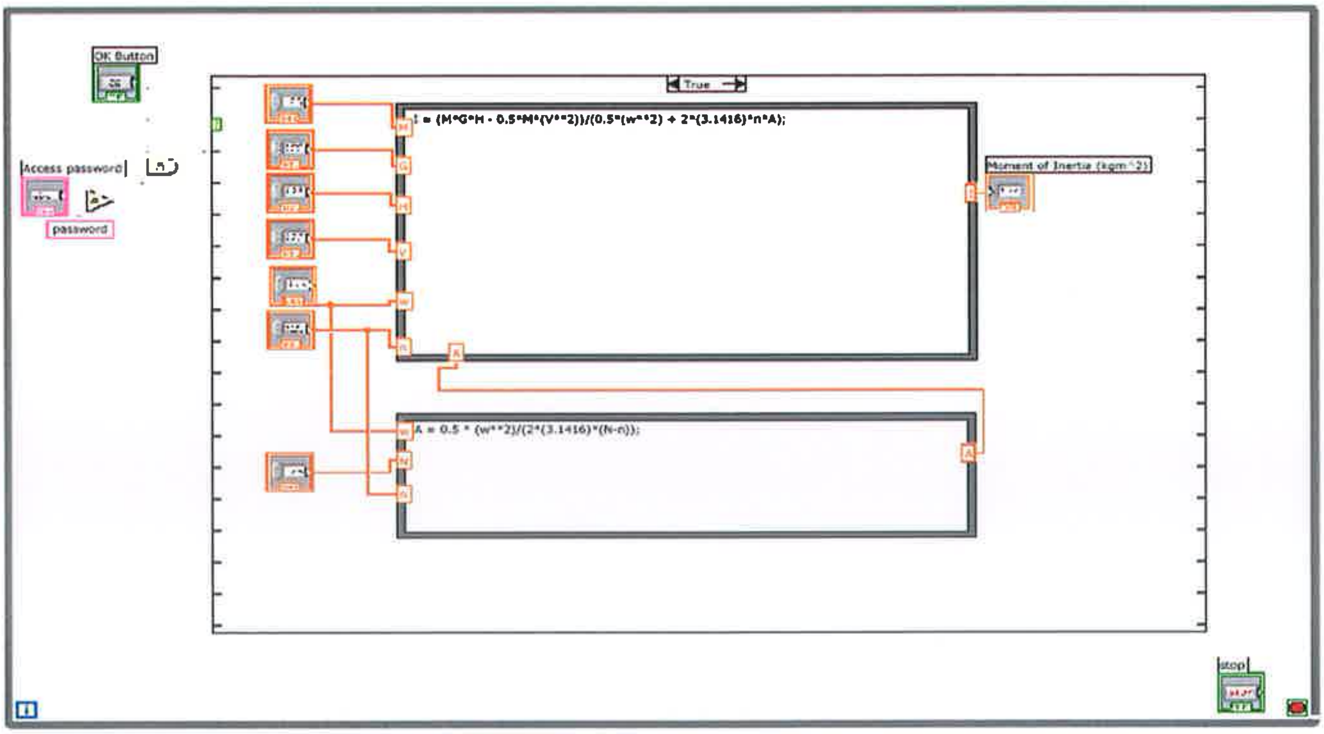

Figure 2.9 Block diagram for the flywheel experiment analysis and theory screen

Directly inside the while loop structure were the two run-conditions required for the program to operate. In this case the correct password must be entered and the Solve Equations Boolean pressed in order for the calculations inside the lower case structures to run. The purple box represents the password function while the green box above it represents the run button which has to be pressed on the Front Panel. These two conditions are wired together at an AND gate which is then wired to the loop containing the calculations. This means that both conditions have to be satisfied in order for the program to run. The orange input boxes on the left hand side represent the tabs where students entered their results into the equations and the orange output box on the right represents the calculated value. The outputted value is the moment of inertia result that the students checked against their own manually calculated answer. Students then proceeded to the final calculation screen which was designed in a similar manner and is shown in Appendix A.

For this module students took their collected data and calculations and composed a report on the experiment which was handed to the demonstrator at the beginning of the next class. The last screen of the VI contained the report requirements and associated marking scheme. This ensured that the students collected all the data necessary to write a high standard critical report. The VI also allowed the students to easily retrace their steps through the experiment if they needed more data.

2.5 Compound Pendulum Experiment

The compound pendulum experiment was the second experiment to be instrumented as part of the same first year mechanics module in which the flywheel experiment was taught.

During this laboratory, groups of four to five students worked together to investigate several concepts relating to the operation of simple and compound pendulums respectively. These concepts were:

1. To investigate the effect of making small changes in amplitude.
2. To determine the radius of gyration of a compound pendulum about its centre of gravity.
3. To investigate the effect of changing the location of the fulcrum.
4. To verify that the periodic time of oscillation for small amplitudes is:

   $$T_p = 2\pi\, [\, (x^2 + k^2_{cg}) / gx \,]^{-1/2}$$

The original setup and procedure of the experiment did not change only the manner in which the students interacted with it. As with the flywheel the compound pendulum VI was based upon a three section design model accompanied by an answer sheet given to the students (Appendix B). These three sections were linked together, in a similar manner to the flywheel, by the home screen, see figure 2.10. The while-loop and case structure format used in the flywheel design was used again to control the flow of the experiment for the students.

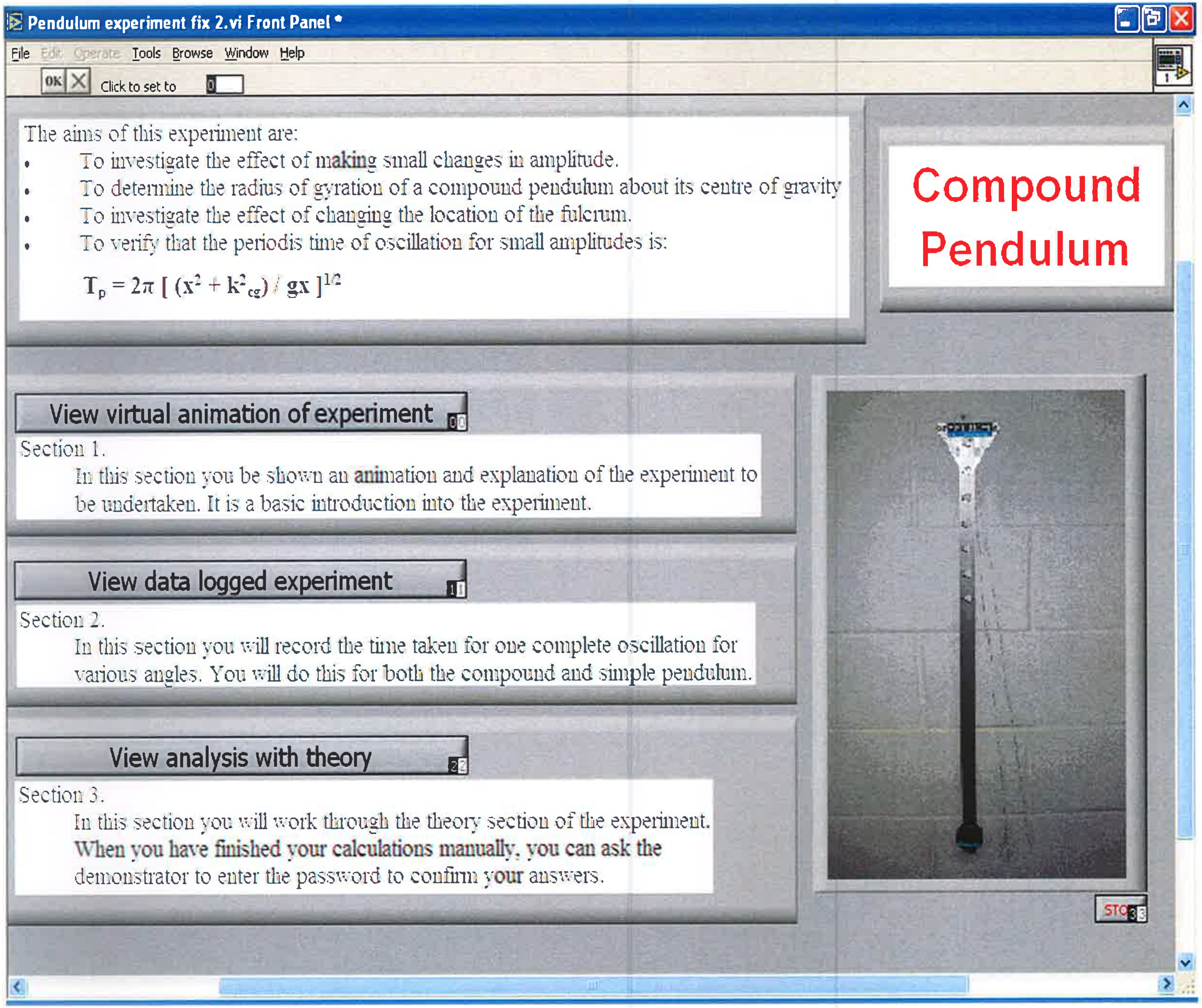

Figure 2.20 Home screen front panel for Compound Pendulum experiment

2.5.1 Compound Pendulum Introduction and theory

As with the flywheel experiment, the animation for the compound pendulum showed the movements of the actual apparatus in operation. An image of the pendulum in use in the first year mechanics lab was drawn using Microsoft paint. The angle of the pendulum in this image was then incremented by an angle of five degrees about its fulcrum and a new image saved at each new position. These images make up the series of frames used in the animation. The demonstrator could easily pause this animation at anytime which allowed for interaction with the students by asking them questions about the transfer of energy from potential to kinetic. At this point the demonstrator could also utilise the introductory questions at the beginning of the students answer sheets. Using this method allowed for the students to be given a thorough introduction into the operation of the compound pendulum. The current version of the experiment, shown in figures 2.10 and 2.11, included several explanatory text boxes which allowed the students to work more unaided. Along with the animation and text boxes explaining the general operation of the compound and simple pendulums a second introduction screen (figure 2.12) was included. This screen gave students an introduction into the theory and calculations that they have to do once they had finished the experiment. These explanations were presented to help students and available for the students to return to later on if they were having difficulties or wanted confirmation on their thoughts.

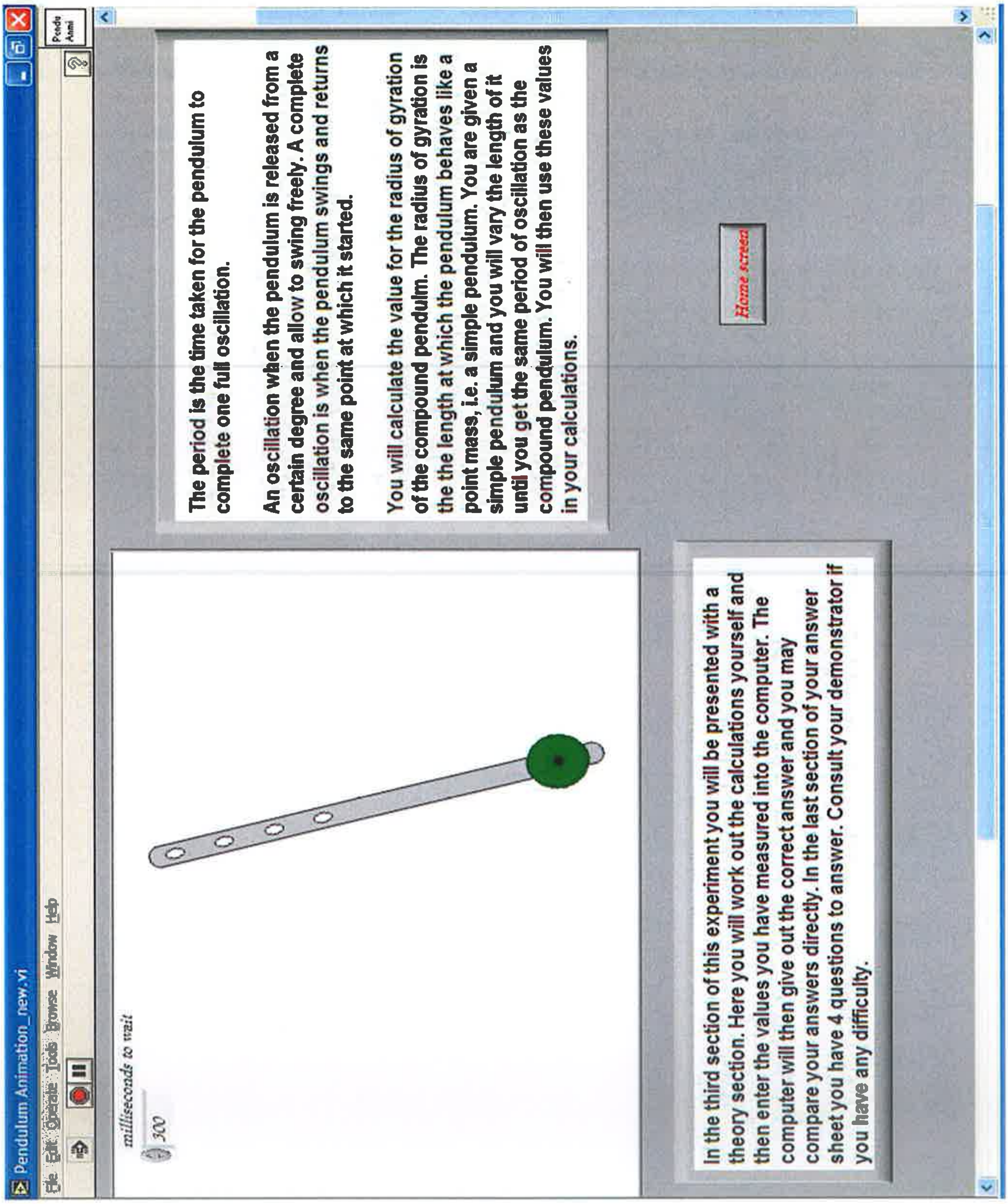

Figure 2.11 Front Panel of the animation screen

for the compound pendulum experiment.

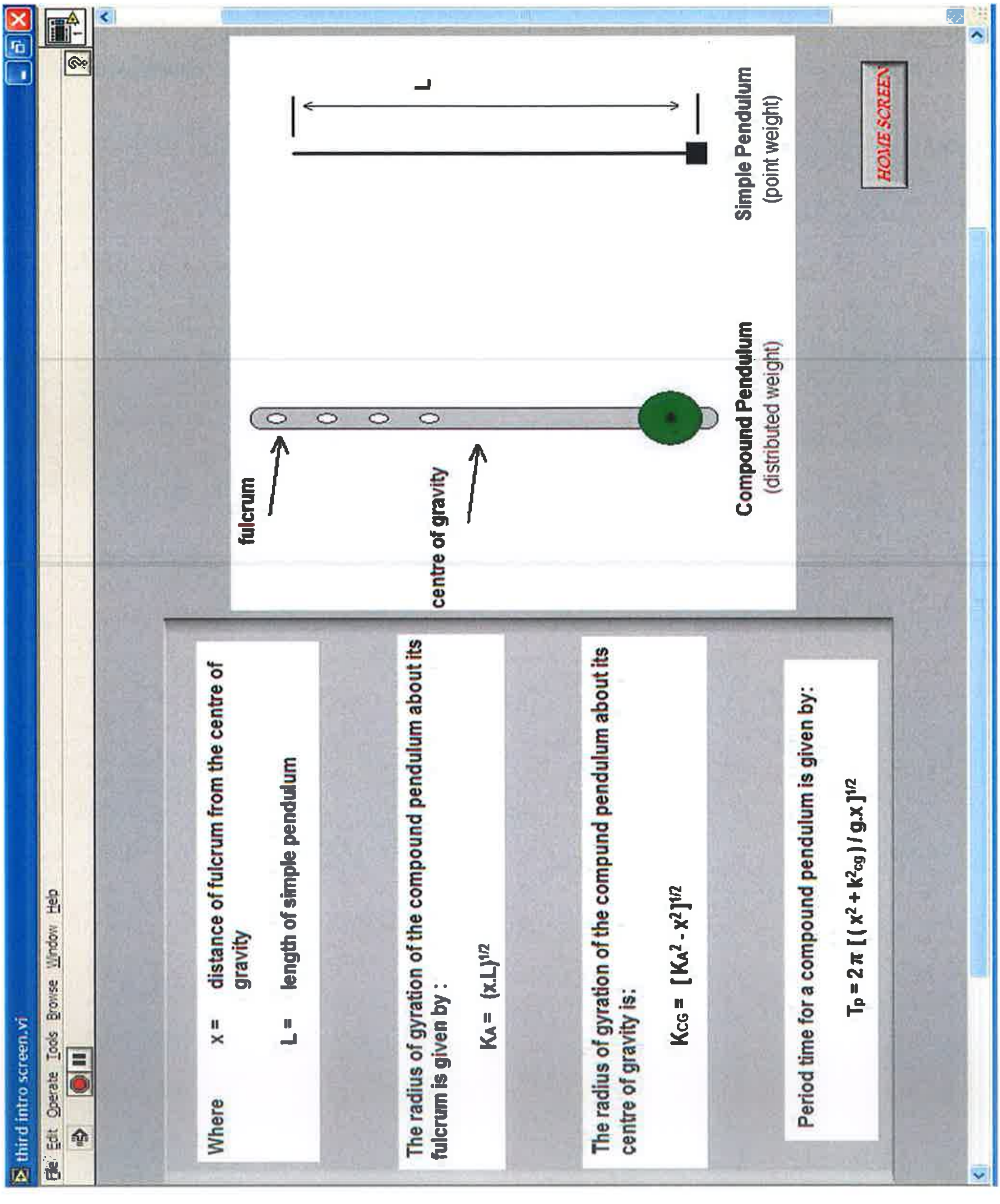

Figure 2.12 Second introduction screen for compound pendulum experiment

2.5.2 Compound Pendulum experimental procedure and data logging

Section two of the experiment is where the students took their measurements and perform the experiment. As with the flywheel virtual experiment the computer did not control any part of the pendulum experiment. An optical sensor was used to record the time it took for either pendulum to complete one full oscillation. The sensor used was a Pepper Fuchs Visolux optical sensor (Appendix D). A National Instruments USB-6009 data acquisition (DAQ) box was used to read from and power the optical sensor. This DAQ boxes contain eight channels of 12- or 14-bit analog input, two analog outputs, 12 digital I/O lines and one counter. This device drew power from the USB bus, so it did not require an external power supply to operate. They included removable screw terminals for direct signal connectivity, an onboard voltage reference for powering external devices and sensors, a four-layer board design for reduced noise and improved accuracy and overvoltage protection on analog input lines up to ±35 V. In addition to ready-to-run data-logging software, each device included NI-DAQmx Base measurement driver software for communication programming of the device in LabVIEW or C. Specification sheets for the USB 6009 can be seen in Appendix D.

As the pendulum broke the beam sent out by the optical sensor a five volt pulse was sent to the PC via the DAQ box. This pulse started a stopwatch in the VI. The stopwatch ran until a third pulse was recorded by the sensor. The time recorded between the first and third pulses represented the actual period of oscillation of the pendulum. These pulses were shown on the data logging screen as the experiment was run. This allowed students to visualise what was happening in the experiment and also introduced them to how the sensor worked. Students then varied the length of the pendulum, according to the procedure, and took more measurements of the period. The sensor and USB DAQ and the rest of the experimental setup are in figure 2.13 and the data logging screen seen by the students in shown in figure 2.14.

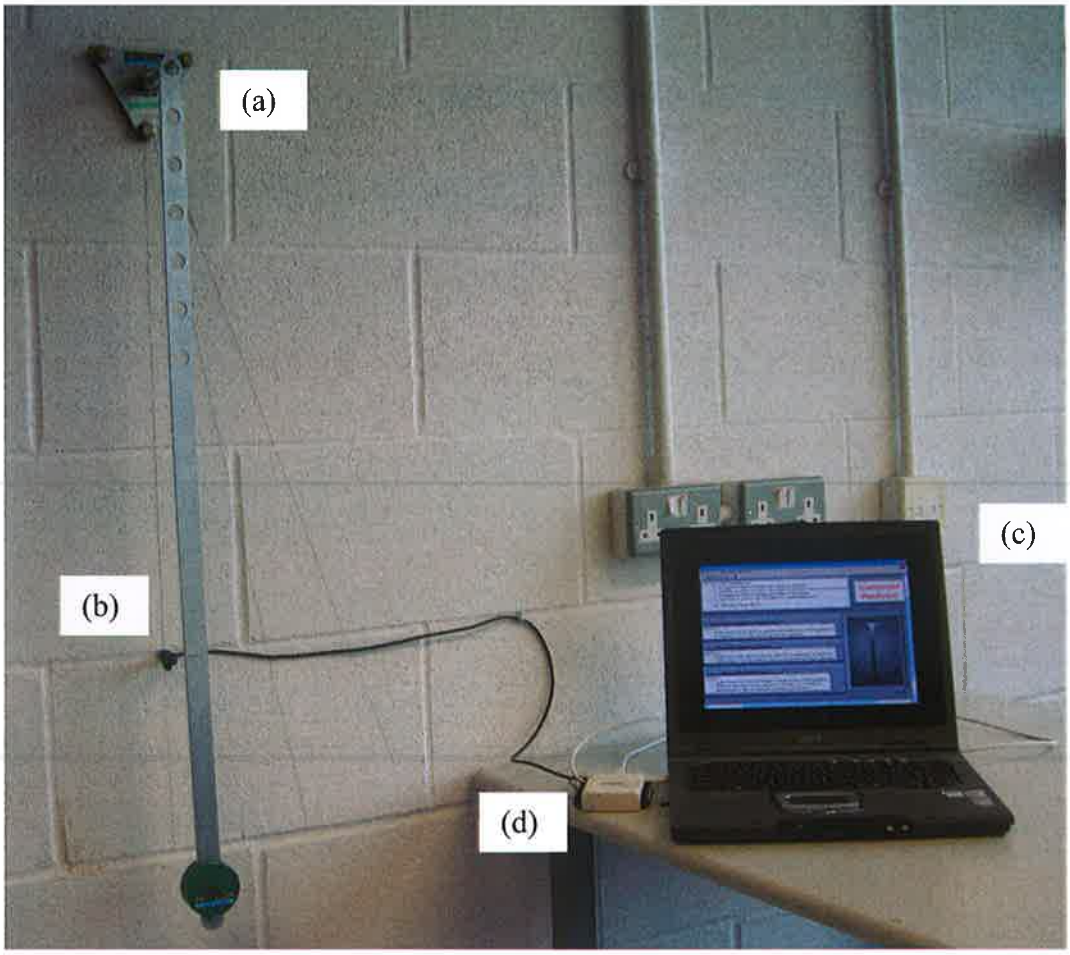

Figure 2.13 Compound Pendulum experiment apparatus (a) compound pendulum (b) optical sensor, (c) VI, (d) USB data acquisition box

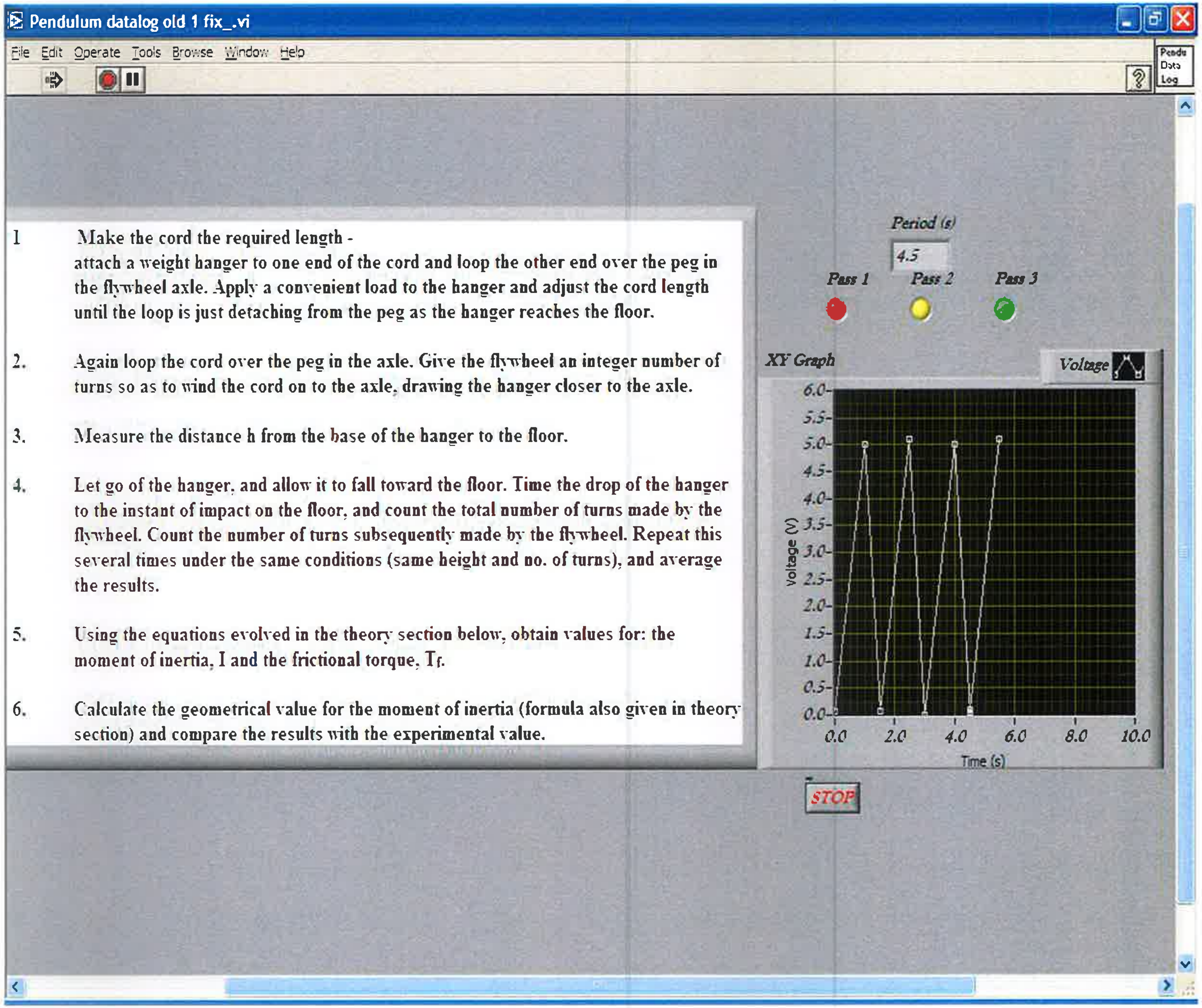

Figure 2.14 Data Logging front panel screen for the compound pendulum

Each pulse in sequence was represented in graphical form in the VI and also was programmed to switch on a light on the screen of the VI to let the student know that the PC had recorded it. All these parts of the VI were running at the same time and caused slightly delayed displaying of the periods of oscillation. This experiment was also designed to be used online. Once the experiment had been run once correctly, the data was collected and saved to a file to be called back as needed in the remote version of the VI. The only difference in the programming of the online version compared with the in house version was the data source. The block diagram from the data logging section is shown in Appendix A.

2.5.3 Compound Pendulum theory and calculation

Section three of the experiment was where students took their results and tried to calculate accurate values for the radius of gyration about the compound pendulum fulcrum and the centre of gravity. They also compared their measured values of periodic time with their calculated values. Students performed their calculations and drew up a table of comparison between the two data sets. Once the students thought they had the correct value they asked the demonstrator to enter a password in the VI in order for them to check their answers. If the students' answers match that of the VI they were permitted to proceed to their final calculations where the same method was applied. The screen showing the calculation of the periodic time for the compound pendulum is shown in figure 2.15. The programming block diagram for this section is shown in Appendix A.

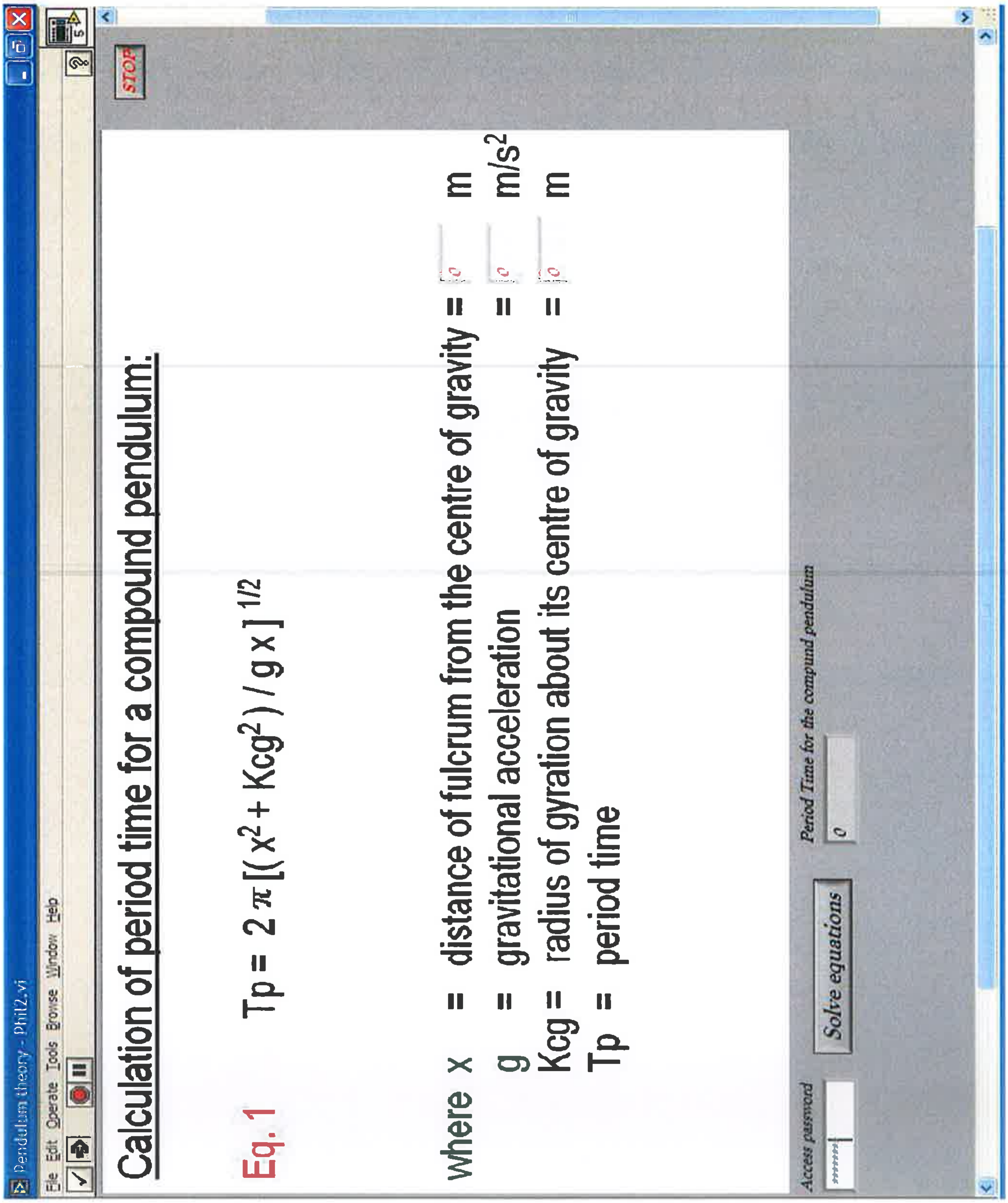

Figure 2.15 Calculation of period screen for compound pendulum experiment.

Once the students have completed all the related experimental tasks they moved onto the multiple choice questions (MCQs) at the back of their answer booklets. The multiple choice questions associated with the compound pendulum can be found in the Appendix B2. As for the flywheel experiment, students took their measured data and calculations and wrote a comprehensive report using the answer booklet for their results chapter. This report was handed in to their lecturer at the beginning of the next laboratory session.

2.6 Centrifugal Force Experiment

The centrifugal force experiment was the third and final apparatus to be instrumented in the first year mechanics module. Hence its setup was similar to those of the compound pendulum and flywheel experiments.

In this experiment, students were asked to relate the magnitude of centrifugal force acting on a body to its rotational speed and radius of rotation. The experimental setup consisted of a speed control unit, tachometer and the centrifugal force rig. Alongside these were a microphone, a USB DAQ box and the computer with the VI running on it. The experimental setup is shown in figure 2.16. The centrifugal force rig consisted of two bell crank hinges fixed to a rotating plate. The plate's speed was determined by the student using the control unit. Variable weights were attached to each of the two arms of the bell cranks during different phases of the experiment.

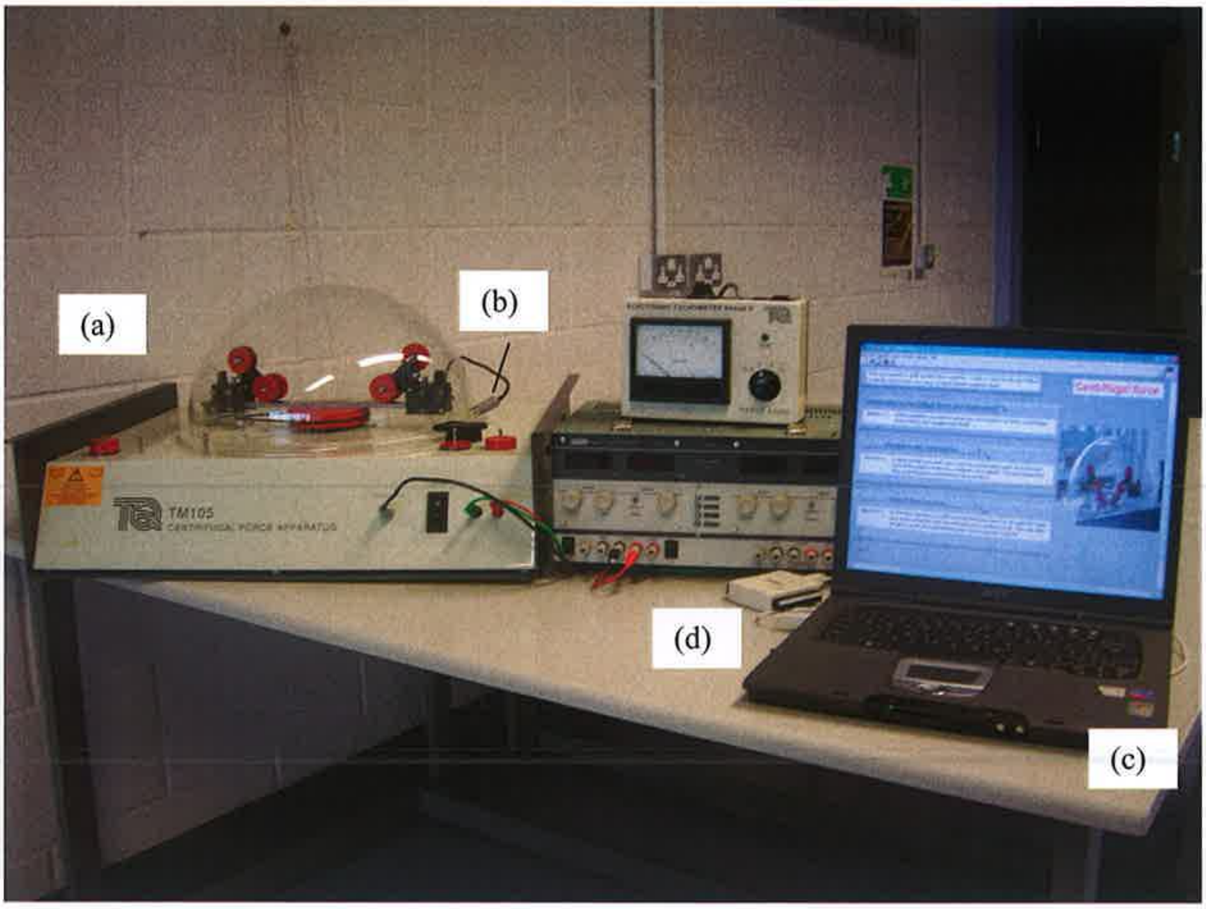

Figure 2.16 Centrifugal force experimental apparatus (a) centrifugal force rig

(b) microphone, (c) VI, (d) USB data acquisition box

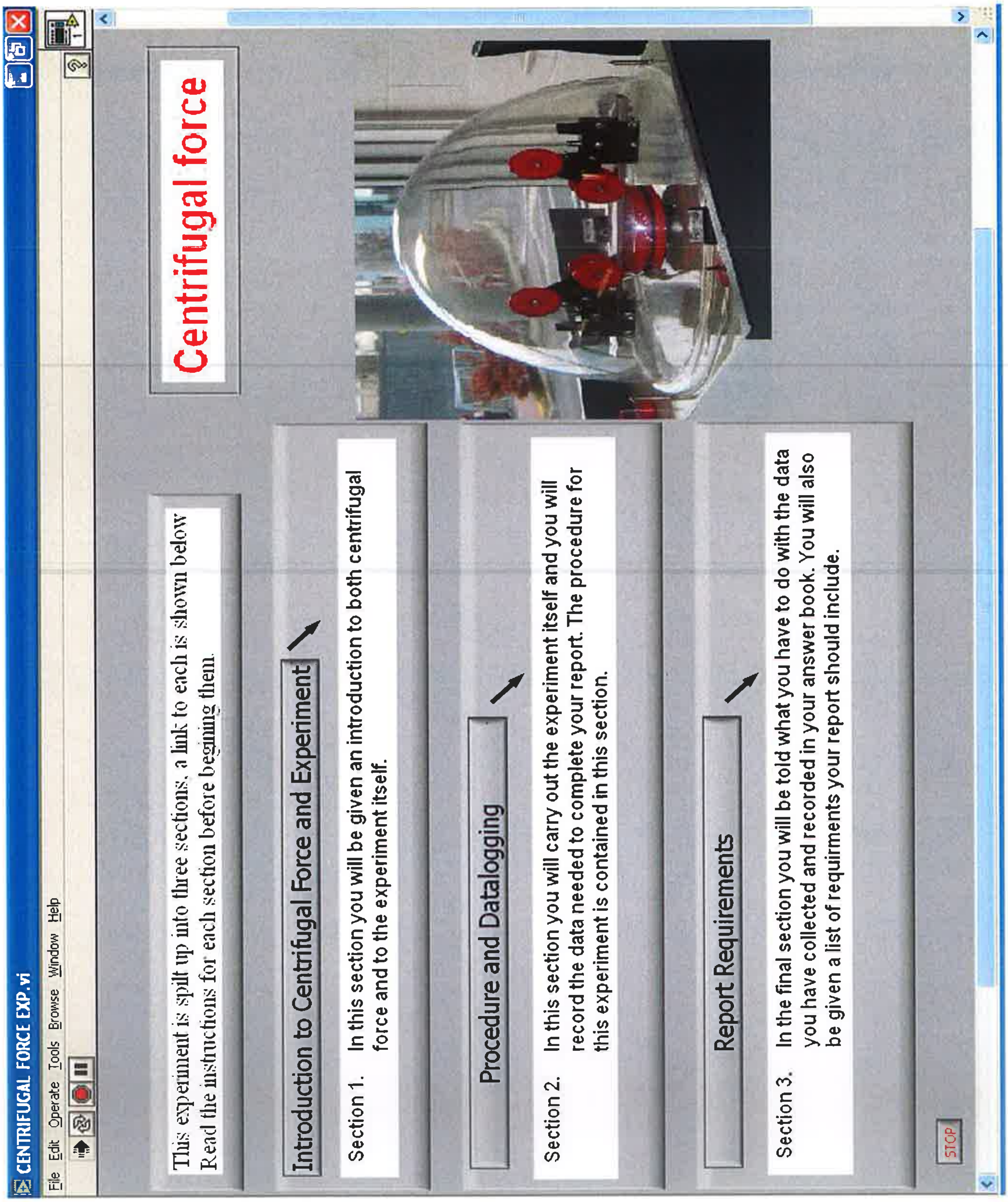

Figure 2.17 Home Screen front panel for centrifugal force experiment

2.6.1 Centrifugal Force Introduction and theory

This experiment required two screens of introduction to allow for the amount of information being introduced to the students. The students proceed to the first introduction screen via the button on the home screen shown in figure 2.17. Here students were given the aims of the experiment and an introduction to the concept of centrifugal force. The second introduction screen gave students an introduction to the particular apparatus that they were going to be use. Two animations were run simultaneously showing animations of side-on and top down profile views of the rig motion. Also shown was how the information given to them on the first introductory screen related to the apparatus. It was during this time that the demonstrator could go through the first questions on their answer booklet to gauge how well the students understood what has been explained to them. If the demonstrator felt that the level of understanding was below the level needed, the introduction could be repeated. This method was useful as depending on the time of year that the student did the experiment, he or she might not have covered the material in corresponding lectures.

The coding for these screens was similar to that of the flywheel experiment and can be seen in appendix A. The animations were designed by taking an image of each of the profiles and drawing a virtual model to match it. This model was then augmented frame by frame to simulate the movement of the apparatus. Although crude by some standards this method ensured that any level of programmer can alter the animations at a later date if needed. It also ensures that this particular part of the program is not too memory intensive and kept the system from hanging or crashing. The first introduction and theory screen is shown in the Appendix A and the second screen with the animations is shown in figure 2.18.

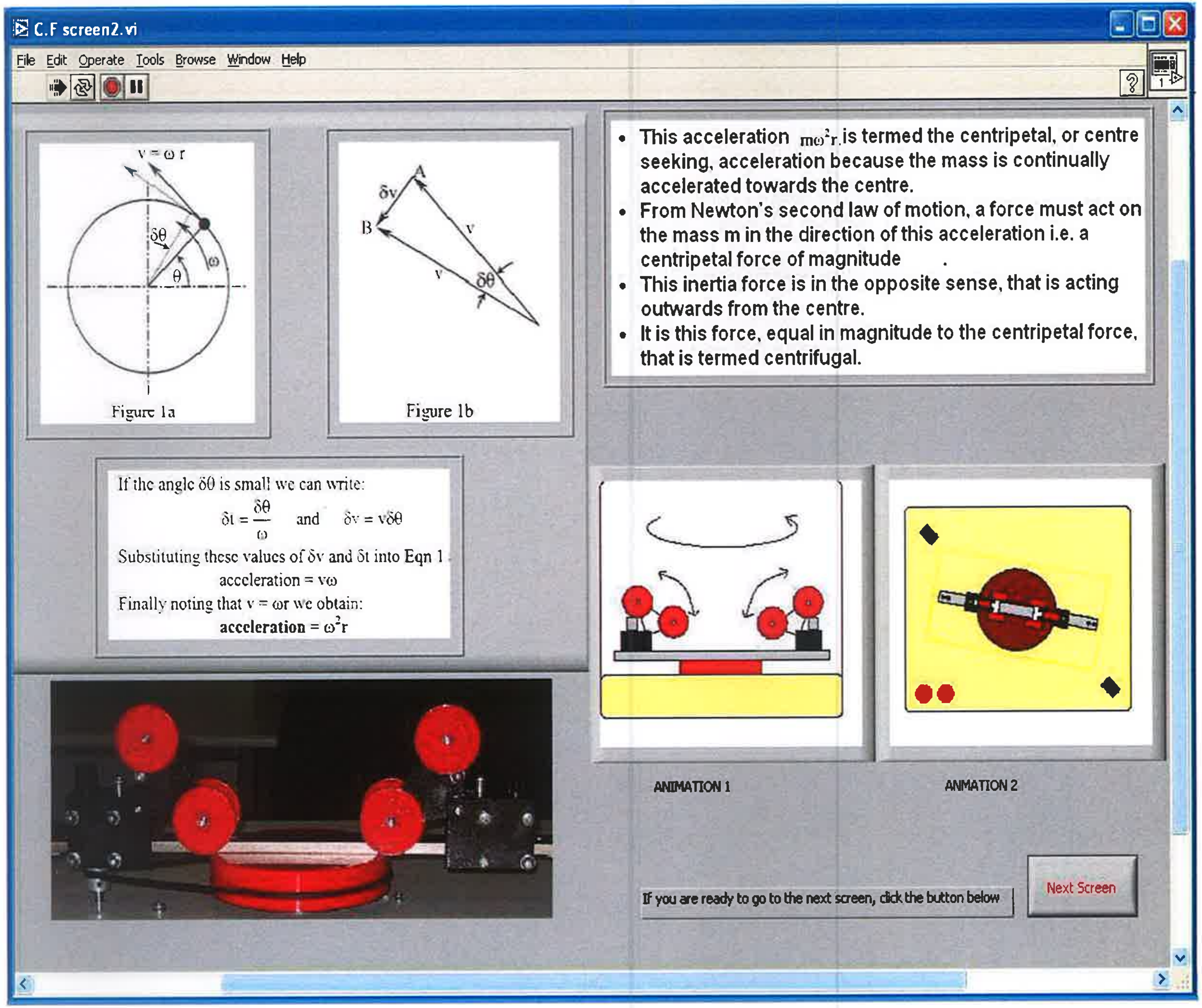

Figure 2.18 Introduction and theory screen two for centrifugal force experiment

2.6.2 Centrifugal Force procedure and data logging

The centrifugal force experiment was the first experiment to have the entire procedure contained within the VI. Due to this the data logging section had an extra screen before the students took any measurements. This screen contained the same content that was presented with in the old traditional laboratory manual. It consisted of the first three steps of the procedure and the equivalent reference diagram for the apparatus. These three steps detailed the set up phase of the experiment before the students began taking any results and is shown in appendix A. The actual data logging screen is where the students recorded their data. Traditionally students would increase the speed until the bell cranks were flung outward with an audible "click". They would then note the approximate speed at which that happened. With the first version of the VI the output from the sensor used by the original stand alone tachometer was used to control the on screen tachometer via a 6009 USB DAQ box connection (appendix D). This however did not provide the students with more accurate rotational speed values. To improve accuracy a second method was tried using a microphone to record the moment at which the bell cranks flung out. A plot of the sound recorded by the microphone was shown in the VI. Once the students had clicked the stop record button, the plot would be saved to the "My Documents" folder in a file name of their choice. This plot would show a clear peak in the middle of the recording and it was taken that this was the "click" heard as the bell cranks flung out. In this method the students would have to calculate the corresponding speed for the "click" rather than read it from the tachometer. With this experiment taking students close to maximum time allowed (three hours), it was prudent to redesign this section. The program used incorporated a graphical plot of the tachometer on screen. The block diagram for the graphical version is shown in figure 2.19 whilst the front panel is shown in appendix A with the initial version using the tachometer is shown in figure 2.20. The design of this experiment allowed for the provision of an online version with a sample data set for the user. This means that either distance or absent students could have a form of access to the laboratory experiment.

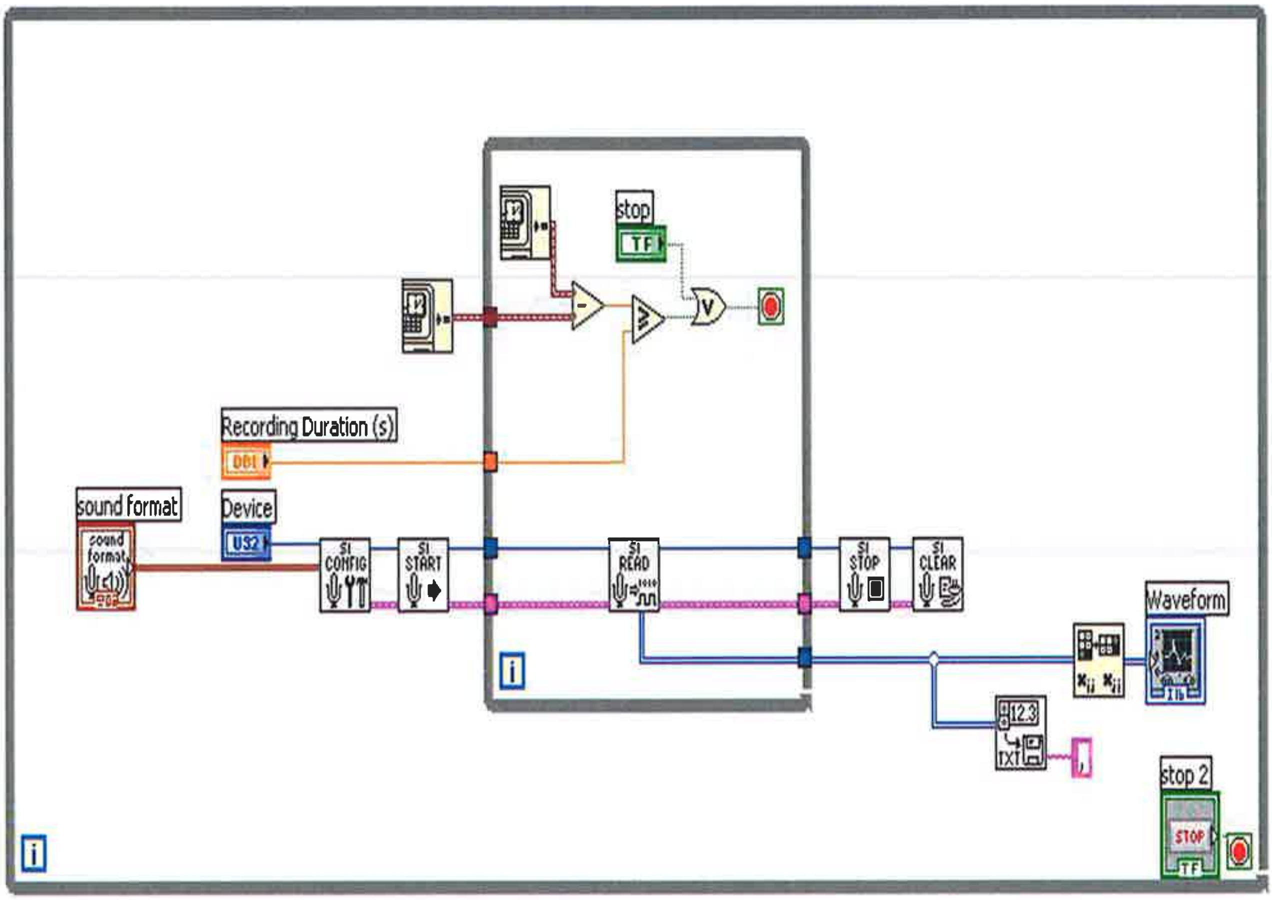

Figure 2.19 Block diagram for sound recording in use with the centrifugal force experiment

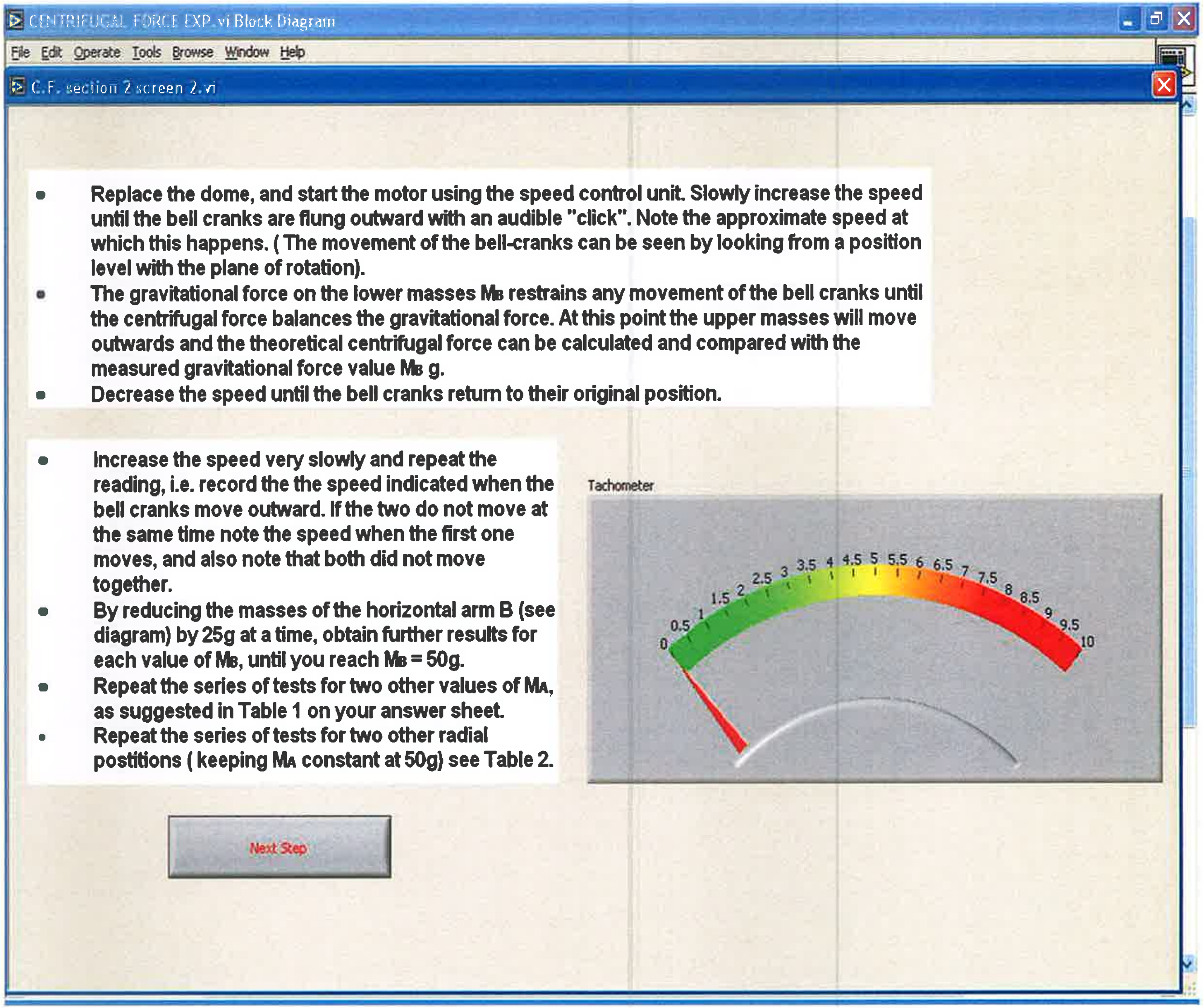

Figure 2.20 Tachometer data logging screen for centrifugal force experiment

2.6.3 Centrifugal force theory and calculation

Section three of the centrifugal force differs from previous experiments in that there was no need for a calculation section. Students were required to collect a large amount of data in two tables. From these tables students plotted gravitational/ radial force (M_B x g) against angular velocity squared ω^2, using a separate line for each mass M_A and plot gravitational/ radial force against ω^2 for a given M_A and ω^2. They also had to plot (M_B x g) against M_A. From these plots students had to make various conclusions and derivations which were to be handed up with their reports. As these plots and derivations were done in the students own time, it was not necessary to include a calculation section in this VI. Section three also contained the guidelines for presenting the report and the marking scheme. Once students went through this they were free to finish off any questions left in their answer booklet and also to complete their MCQ's. Section three of this experiment is shown in appendix A.

2.7 Linear Variable Displacement Transformer (LVDT) and Accelerometer Experiment

The LVDT experiment is part of an instrumentation and measurement laboratory given to third and fourth year engineering students. The level of complexity involved in this experiment was higher than that of the experiments previously instrumented.

The setup of this laboratory was different to the setup of previous undergraduate laboratories where previous VI's were in operation. Several setups of the experiment were also in use in the laboratory at one time meaning that there was much more interaction within individual groups. The objective of the experiment was to use the LVDT and an accelerometer to determine material and dynamic properties of a beam. The experimental setup consisted of a suspended metal beam fixed in position at one end, a LVDT, an accelerometer, a power supply and an oscilloscope, see figure 2.21.

Due to the higher level of understanding required to complete this experiment it was decided that the introduction section of the corresponding VI should be longer in order to be completely comprehensive in its explanations. Despite the added intricacy of the LVDT experiment, the same three section model was employed. In section one, thorough accounts of how the LVDT and accelerometer operate were given. Once students had finished these they were asked to complete the corresponding section of their answer book by their demonstrator to ensure they understood the concepts. Once they successfully completed this, students continued on to the next section which explained the calculations involved in the experiment.

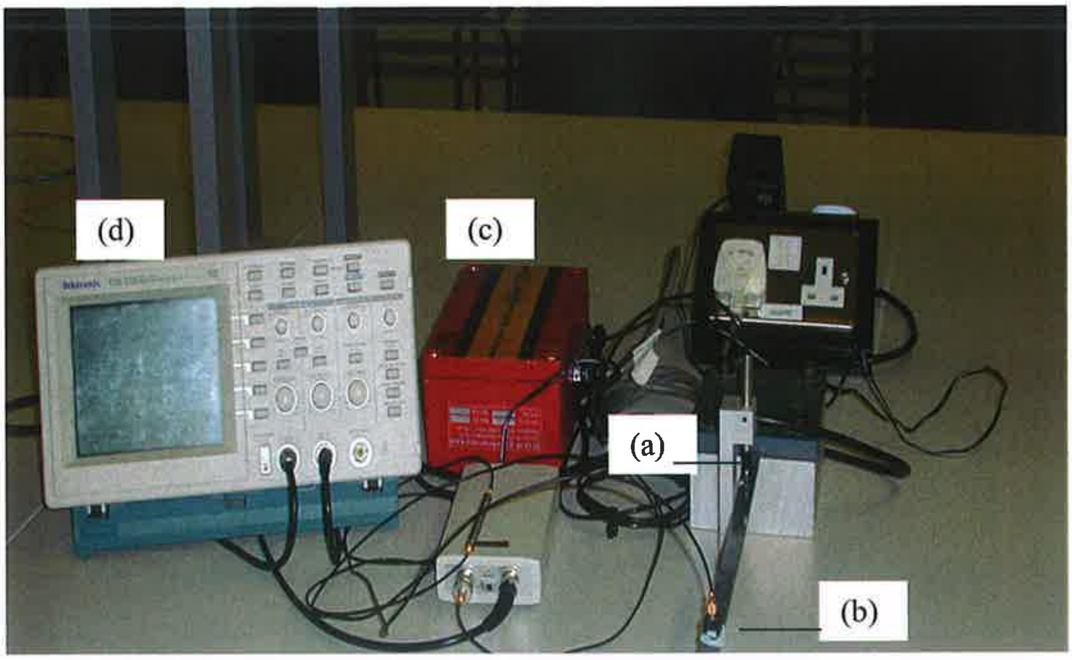

Figure 2.21 Experimental set up for LVDT experiment. (a) LVDT, (b) accelerometer, (c) power supply and (d) oscilloscope.

Notes on nodes and antinodes, fundamental frequency and how to measure the natural frequency of the beam were also given here. In the third and final section the students were given the procedure required to carry out the experiment. This section also contained the data logging were the computer recorded all the data needed for the students to complete the experiment.

2.7.1 Introduction to the LVDT and accelerometer

A LVDT is used to measure the linear displacement and velocity of an object and it is essential that students undertaking this experiment leave knowing how this is done. LVDT's consist of a moving ferrite core and a set of coils: one primary and two secondary. In normal operation the shaft is connected to an object (in this case the beam) and an ac magnetic field is introduced on the primary coil. As the LVDTs shaft moves away from centre, the result is an increase in voltage of one of the sensor secondary coils and a decrease in the other. This results in an output from the measurement sensor. An animation showing a cut away of a LVDT with its core moving in between the three coils is included in this explanation, see figure 2.22.

This animation allowed students to see an LVDT in operation and apply the concept to the experiment that they were involved in. On seeing the animation and the further explanatory screen (Appendix A) students could move the actual LVDT and attached oscilloscope present to test the knowledge they had just learned. A similar approach was used on the next screen to explain the operation of the accelerometer (Appendix A). Descriptive text boxes were present throughout this section allowing for students to work in a more unaided fashion.

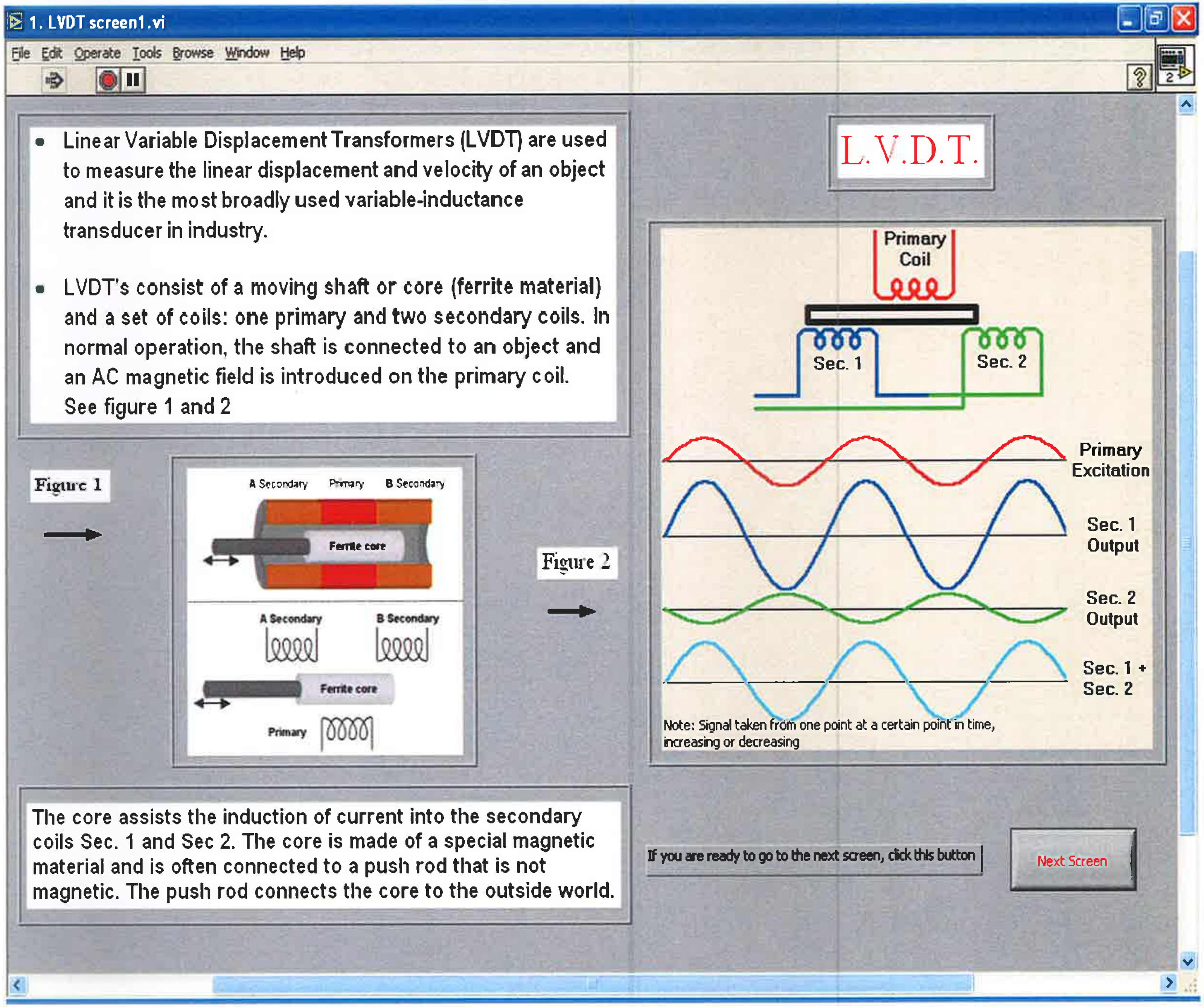

Figure 2.22 Introduction animation screen one for LVDT experiment

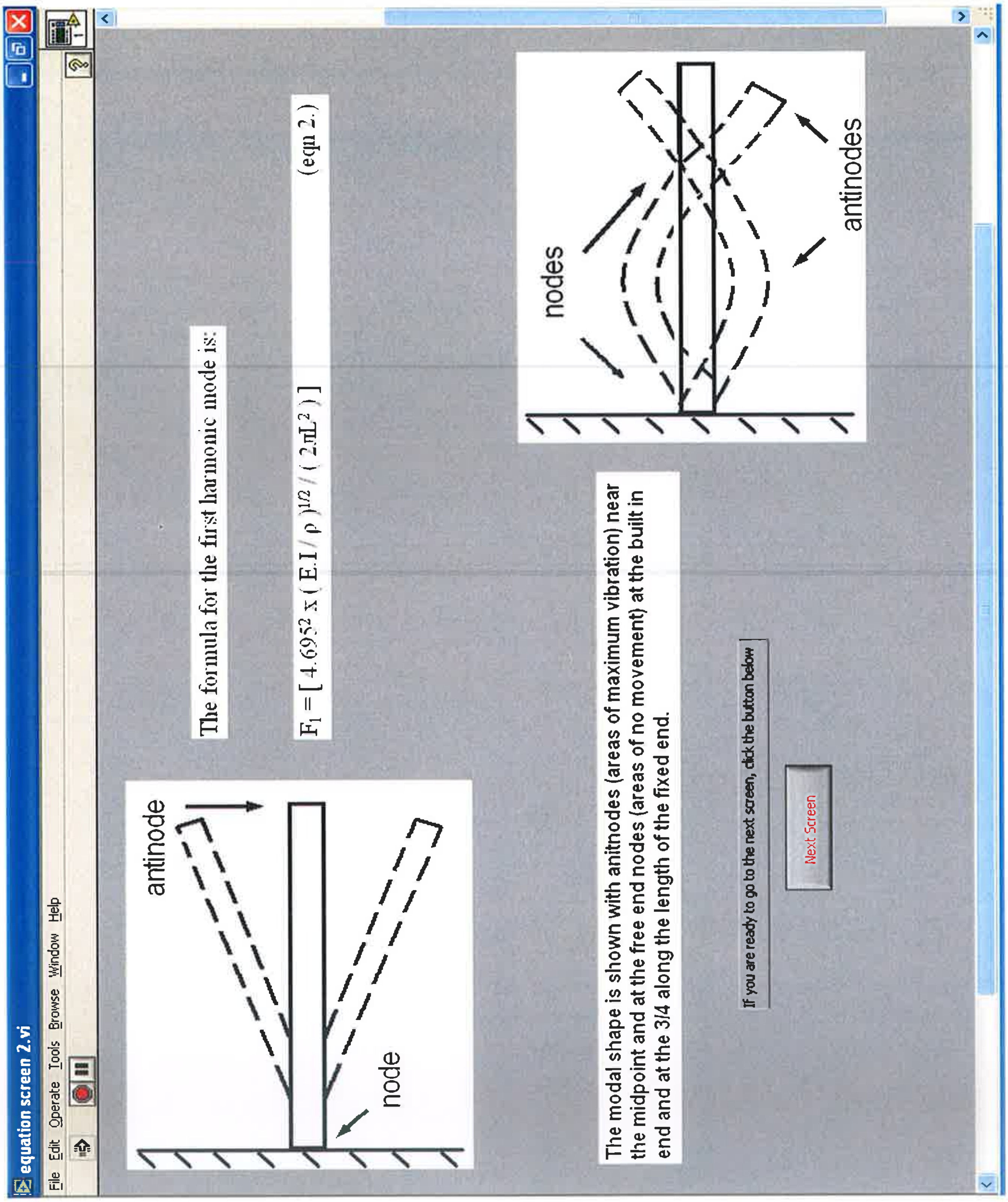

Figure 2.23 Node and antinodes screen from section two of LVDT experiment

2.7.2 Section Two, Notes on calculations and terms used

As mentioned previously, it is important for students to know why they are doing a particular experiment or calculation. In section two of this VI students were provided with a detailed introduction to the calculations and to the terms associated with them. This section was similar to and continued on from section one. Students were brought through the calculations for the fundamental frequency, the first harmonic mode, the natural frequency and the sensitivity of the LVDT. Explanations of each term and descriptive images were included to aid the student's understanding. As with the first section, section two was accessible to students at any time throughout the experiment. This allowed students to refer back any time they felt necessary, reducing the demand upon demonstrators time. Figure 2.23 shows the node and antinodes explanation screen used in section two of the LVDT and accelerometer experiment.

2.7.3 Measurements, data logging and report

As this is a more complex experiment a slightly different approach was employed when designing it. Sections one and two dealt with the experimental apparatus and with the theory which is normally left until the end of section three as it was in previous VI's. Section three for the LVDT and accelerometer contained five screens in total. Three of these were procedure and data logging screens, one is a further explanation screen on how to process data and the last screen dealt with the report requirements. Each of the three data logging screens initially were made up of procedural text boxes and a graphical representation of the outputs of the accelerometer and the LVDT. It was found that the oscilloscope was still needed to adjust readings and compare measurements taken by the students and so an oscilloscope was incorporated into the programming of each of the three data logging screens. The outputs from the accelerometer and LVDT were read directly in to the PC using a USB-6009 (Appendix D) but were powered by a separate power supply.

Students perform each of the three data logging sections and read their data directly from the virtual oscilloscopes and used that data to plot the graphs required in their reports. One of these screens is shown in figure 2.24. The final explanation screen instructs students on how to graph a comparison of their results to theoretical results. Such a graph is included in their reports and students must derive reasons that their results may differ from theoretical values. Finally students are free to finish off the multiple choice questions given at the end of each experiment.

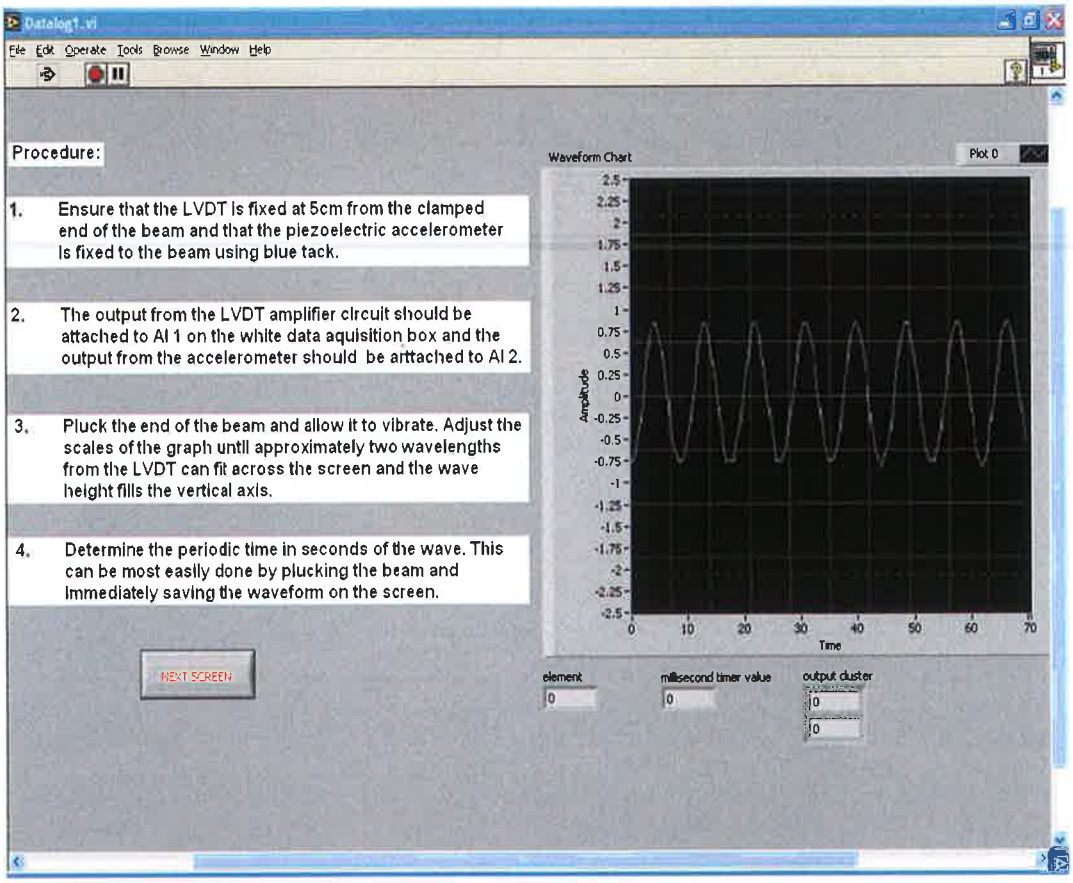

Figure 2.24 Data logging screen for LVDT and accelerometer experiment

2.8 Load Cell Experiment

The Load Cell experiment was part of the same laboratory module as the LVDT experiment and it contained the same level of complexity in its design. It is taught to third and fourth year engineering students in a three hour lab session.

The objective of this experiment was to calibrate a load cell and to determine some of its static performance characteristics. The load cell was placed in compression using a mechanical press and the output from the load cell was compared to readings provided by a button load cell which was assumed to give the true value. The load cell was configured as a full bridge using four strain gauges mounted so that two would be in tension and two in compression when the cell was loaded. Students must therefore be given an introduction to strain gauges independently, before they can see how they work as part of a load cell. This was covered in the introduction section and completed before they could move on to the procedure and data logging sections. The load cell VI had to be designed differently as it was taught in a different order to the manual layout. The particular lab instructor in charge of teaching this experiment had modified the method in certain parts to suit his own style of instruction. Due to this, the VI was designed to match his preferred teaching style. Several theory screens were also included in the procedure section to guide students through the more difficult parts of the experiment. Finally section three of the VI contained the analysis and calculation theory explanation screens. This instructed students on what to do with their collected data and on how to present it in their report to be handed up at the start of the next laboratory session. Figure 2.25 shows the home screen for this VI.

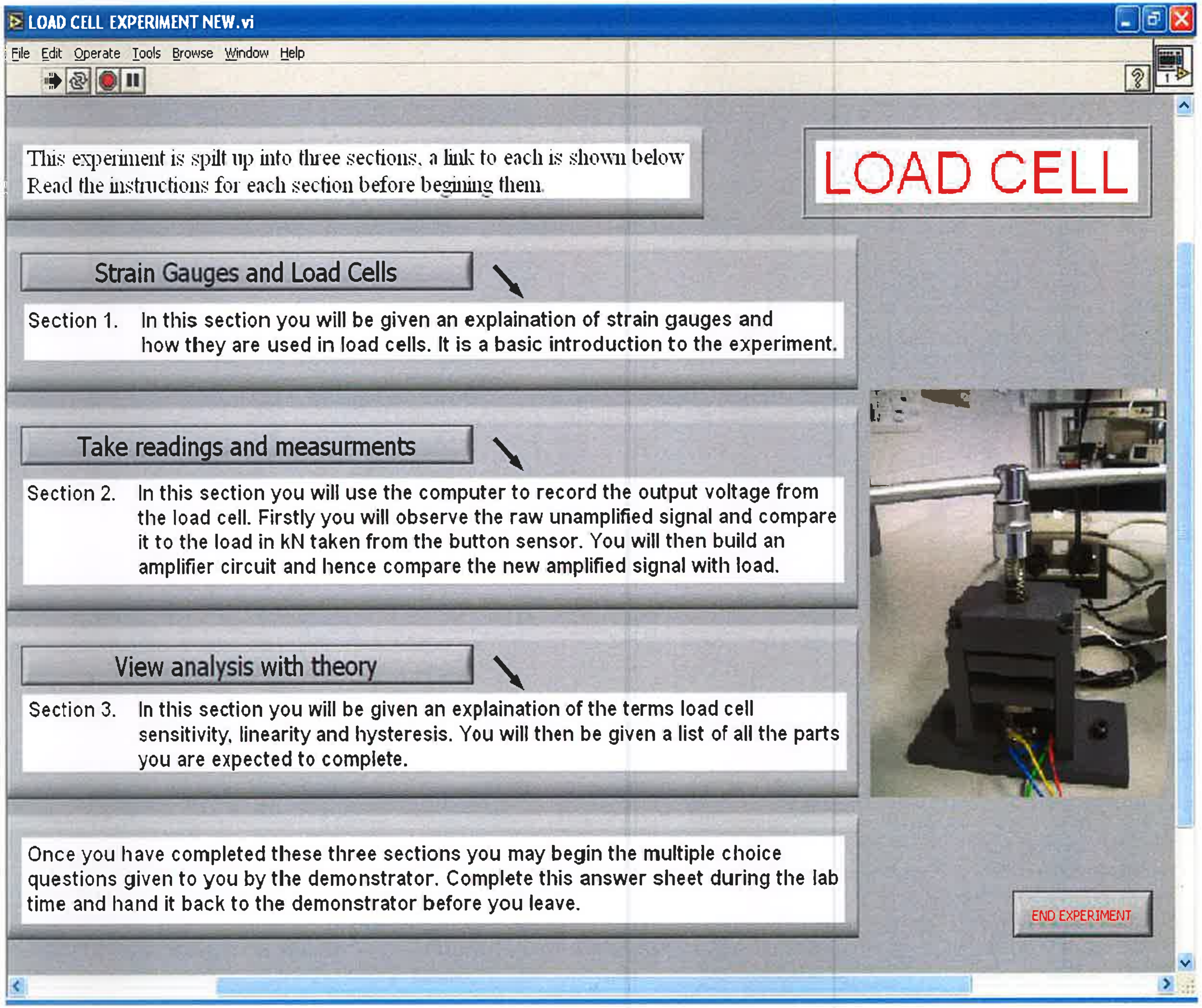

Figure 2.25 Home screen for Load Cell experiment

2.8.1 Introduction to Strain Gauges and the Load Cell

A load cell is a transducer which converts force into a measurable electrical output. Although there are many varieties of load cells, strain gage based load cells are the most commonly used type and are the type in use in this experiment. Therefore in order to understand the operation of the load cell, students must first understand the operation of a strain gauge. On the first screen of the introduction students were giving a thorough introduction to the design, make up and operation of a common strain gauge. This screen showed how the gauge reacts to tension applied longitudinally and also how it is insensitive to lateral forces. This lead students to the next screen which explained how four separate strain gauges are used in the operation of a load cell. Students were shown a looped animation of a load cell being compressed repeatedly. Two of the gauges were in tension and two in compression and were wired with compensation adjustments. When weight was applied, the strain changed the electrical resistance of the gauges in proportion to the load. Students were then introduced to the load cell configuration represented on a simple circuit diagram with a Wheatstone bridge. Wheatstone bridges are used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. In this case the unknown value is the strain and students were shown how to derive its value. The animation for this screen was in the form of an imported GIF (Graphics Interchange Format) picture file and the textual information was taken from the original manual used by students in previous laboratories. The first introduction screen can be found in Appendix A whilst figure 2.26 shows the second introduction screen for the load cell experiment.

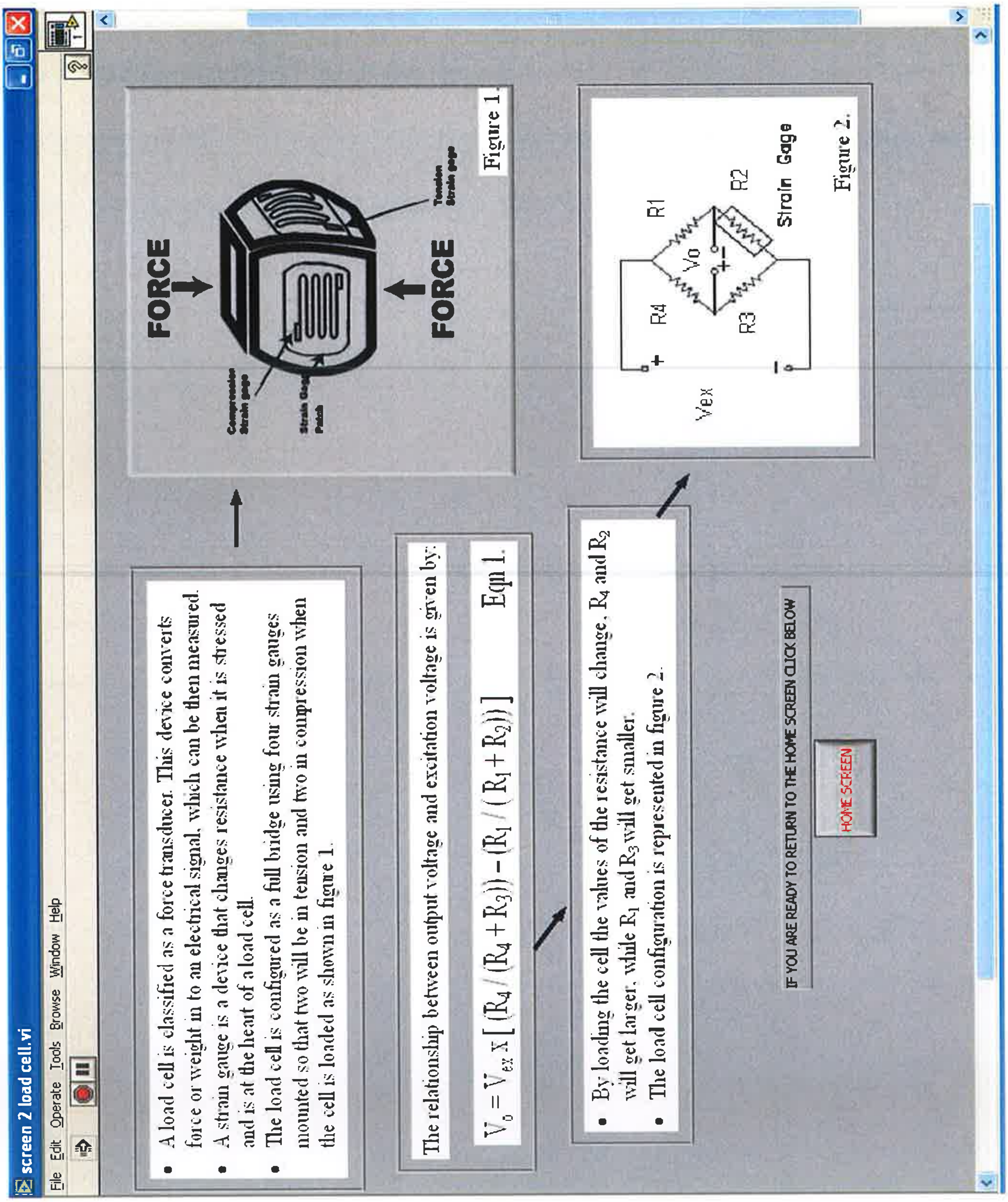

Figure 2.26 Second introductory screen for load cell experiment.

2.8.2 Section Two, Taking Readings and Measurements

The procedure for the entire experiment was contained in section two of this VI. Students began this section with a reminder of the objective of the experiment before undertaking any work. Students then setup their apparatus and powered up the load cell. They applied loads by means of a manually operated mechanical press seen in the image in figure 2.25. A button load cell was placed as a control in the press to give the students a read out of what load they were applying. Beginning at 0kN, students increased the load in steps of 5kN up to 30kN. The output from the un-configured load cell was recorded with the VI via a USB DAQ box attached to the circuit. A graph of mV output from the cell against load in kN was displayed on the screen. Students had to reproduce a similar graph in their laboratory report to be handed up. It was important to show students the linear plot associated with this data set in order for them to understand and discuss why it was linear. Students were also prompted to take a look at the mV output levels of the load cell to lead them in to the next section of the experiment involving signal amplification. It was at this time that students were encouraged to discuss problems with such a low level voltage output and what they could do to enhance it. Once they did this they were given an explanation of an amplification circuit and how it could be applied to the current load cell configuration. Students manually built an amplifier circuit and wired it in to their experimental setup with the USB DAQ box still attached to the now amplified output of the load cell. Students repeat the steps of applied loads in increments of 5kN up to a level of 30kN and plotted their results on the computer. They then had two sets of data for the experiment, either amplified or not amplified. The data logging and explanatory screens for section two can be seen in Appendix A.

2.8.3 Section Three, Analysis and Theory section

Section three for the load cell experiment is quite short in comparison to other VI's. This was due to a lot of the theory and explanations having been undertaken during the procedure. In section three students were given a description of the calculations they had to perform on the data they collected from the load cell. These screens were similar to the introduction screens in previous VI's and were relatively simple in design. Students were shown how to calculate the sensitivity and linearity of the system and also what each of these terms mean. On the final screen they were given an explanation of hysteresis and how to derive it. These screens were written using images from the original manual and explanatory text boxes. Finally students were shown the specific report requirements screen for the experiment. This provided a check list for what was to be completed and handed up to the demonstrator in their report. Students also had to complete the multiple choice questions associated with this experiment. Questions on strain gauges are also included here to ensure that students understood all of the experiment from the beginning to the end point. A copy of these questions and the full VI can be found in appendix B 2.

2.9 Capillary Viscometer Experiment

The capillary viscometer rig was originally designed and built by a engineering student as part of his Masters degree. Since its completion it has been prepped and modified to be used as a demonstrational experimental apparatus in both undergraduate and postgraduate laboratory sessions.

Students have a three hour laboratory session in which they learn about the operation of the capillary viscometer and the processes associated with it. This experiment had larger groups of students attending it as there is only one apparatus for them to observe. Laptops with the VI loaded were present in the lab in order to ensure that each student had access to the material. One of the computers was also used for data logging and control of the apparatus. Data collected from this computer was emailed to the students once the lab had ended.

There were four main sections in the viscometer assembly. These are the piston motion section, the injection chamber with surrounding furnace, the capillary with surrounding furnace, and the quench tank. The piston was connected through an adjustable drive chain, including a rack and pinion, servomotor, which was controlled via the PC and a controller. Injection pressure was made measurable throughout the stroke via a load cell integrated into the injection system. The billet chamber leads into a conical section. Thermocouples allowed system temperature measurement and were used to feed back to a temperature controllers which controlled the power output from a 2 kW band heater around the injection chamber. A quartz rod loading pin was used to transmit the fluid pressure from near the start of the capillary (40 mm in from the narrow end of the conical section) to a button load cell held in a ceramic enclosure beneath the table. This pressure sensing transducer allowed for the fluid pressure to be monitored. The signals for the temperature sensors and the pressure profile were measured against time by a the VI . Students used this sub-VI as part of the larger VI designed to teach them the operation and principles of high shear rate viscometry. A schematic diagram of the apparatus is shown in figure 2.27.

As there is a large amount of material associated with the capillary viscometer a much larger introduction section was needed in this VI. Also as this is a demonstrational experiment, the design of the accompanying VI had to match it accordingly. This VI was also made available for students to download so that they could go over what they had seen and run the experiment again with sample data included.

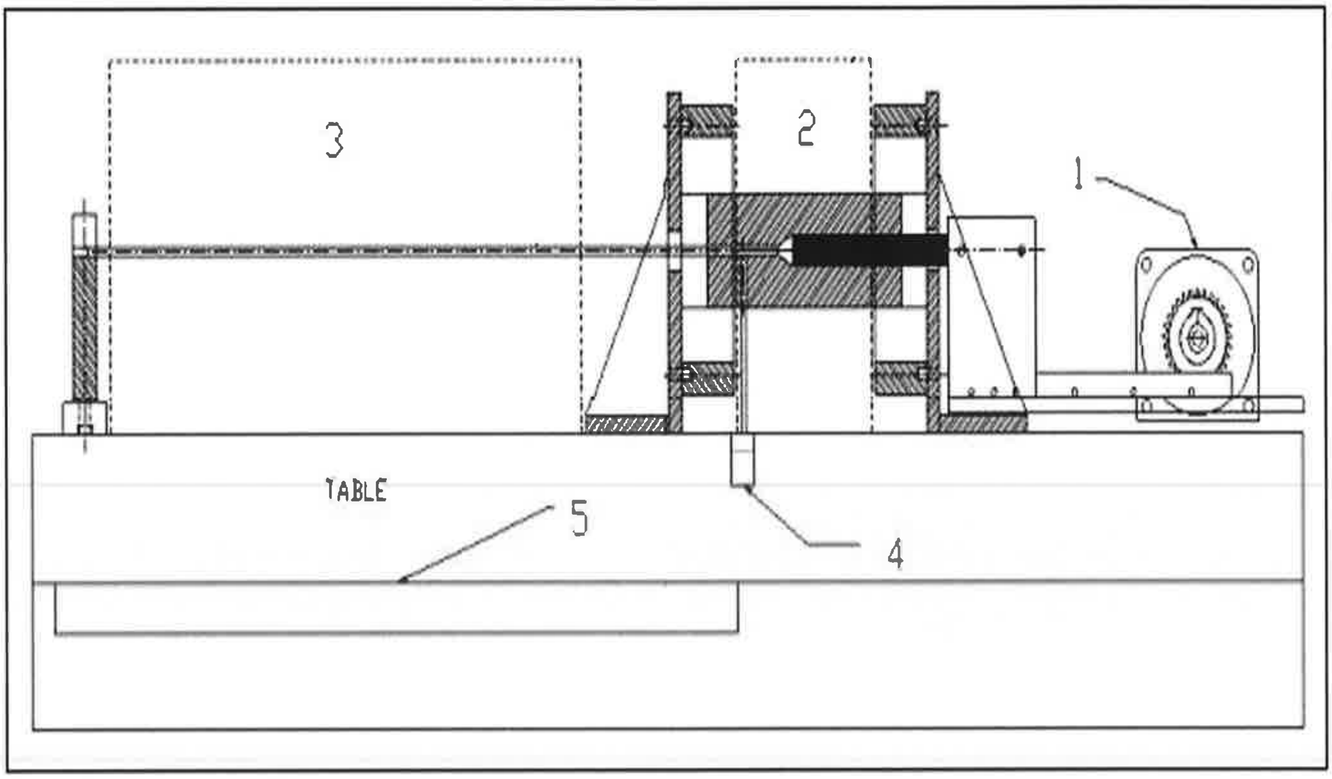

Figure 2.27 Schematic of the capillary viscometer (1) represents the piston motion mechanism, (2) the injection chamber with surrounding furnace, (3) the capillary section, (4) the load cell, and (5) the quench tank for the capillary after billet injection.

2.9.1 Capillary Viscometer Introduction and Theory

The introduction section to this VI needed to be larger than previous experiments due to the large amount of information associated with the capillary viscometer and its related processes. The introduction and theory section was split into four separate sub sections to give students as complete a level of instruction as possible. Also this allowed for students to revisit one particular section in case of query without having to run through all the other screens to get there. These four sections include a general introduction to plastics, statistical design of experiments, semi solid metal (SSM) processing and injection molding. The plastics section, being the most general is the largest with five explanatory screens; the statistical design of experiments and SSM processing needed three; and the injection molding section needed two. These thirteen screens in total take some time for students to get thorough and to understand. This was convenient however as the plastic billet within the apparatus took a similar time to reach it's optimum temperature for injection. During this time students could converse with each other and with the demonstrator as needed. The information contained in the explanatory screens lead students to ask more informed questions relating to the apparatus as they progressed through the experiment. Figure 2.28 shows an explanatory screen from the SSM processing section of the VI. The full set of screen shots of the complete VI is located in Appendix A.

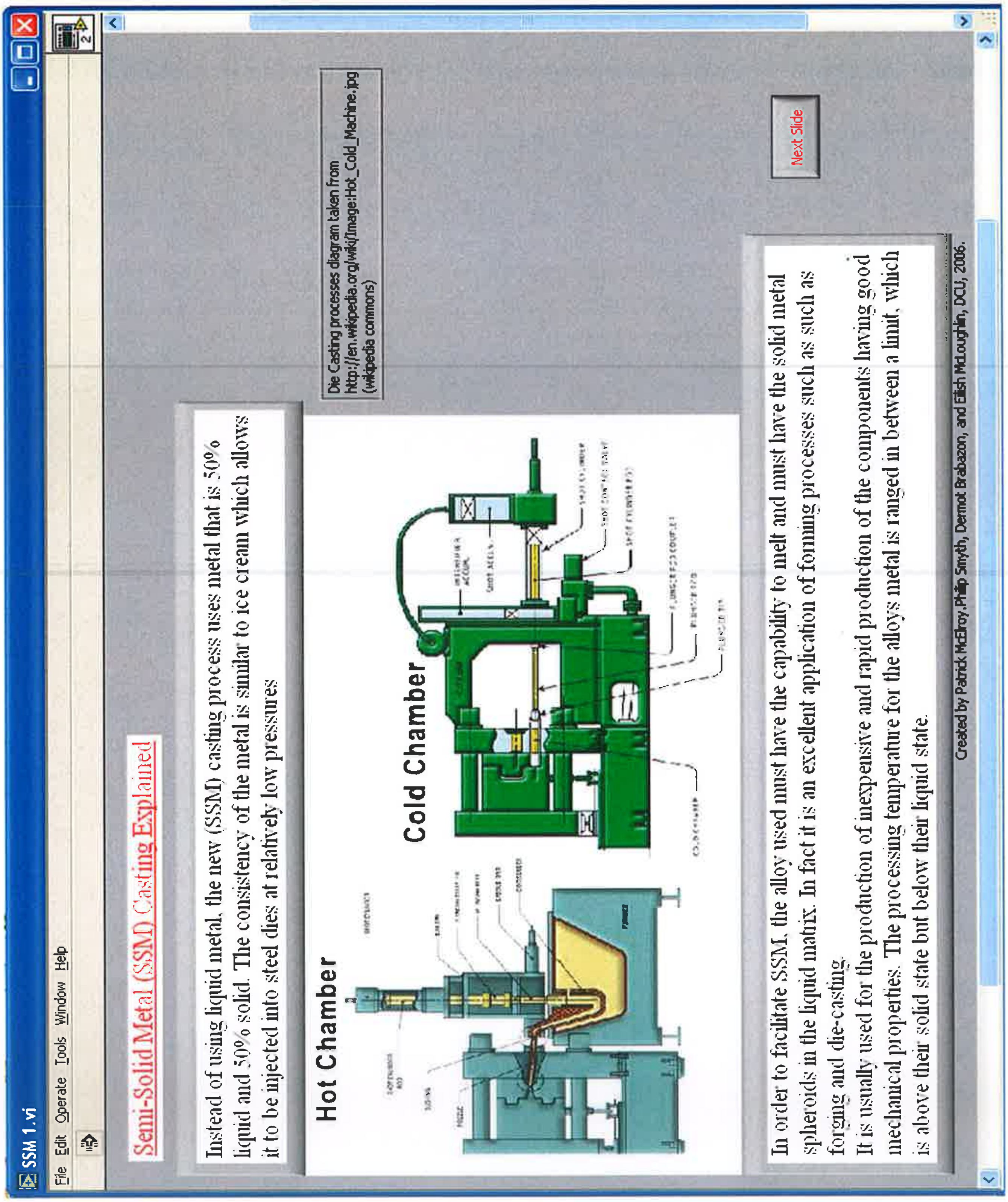

Figure 2.28 SSM processing screen, capillary viscometer experiment.

2.9.2 Section Two, Procedure and Data Logging

Normally in section two the procedure was written so as to facilitate the students can carry out the experiment themselves and record the data needed to complete their calculations. As this experiment was performed by a demonstrator, the procedure for this section was only included so students can follow exactly what is going on during the experiment.

The input for the motor control and the outputs from the load cell and thermocouples ware all wired into the National Instruments DAQ box, shown in figure 2.29. Once the experiment was run all the data was recorded and stored on the computer to be emailed to the students to complete their reports. Figure 2.30 shows the data logging screen.

Figure 2.29 Picture of (a) temperature controller, (b) National Instrument data acquisition box and (c) motor controller.

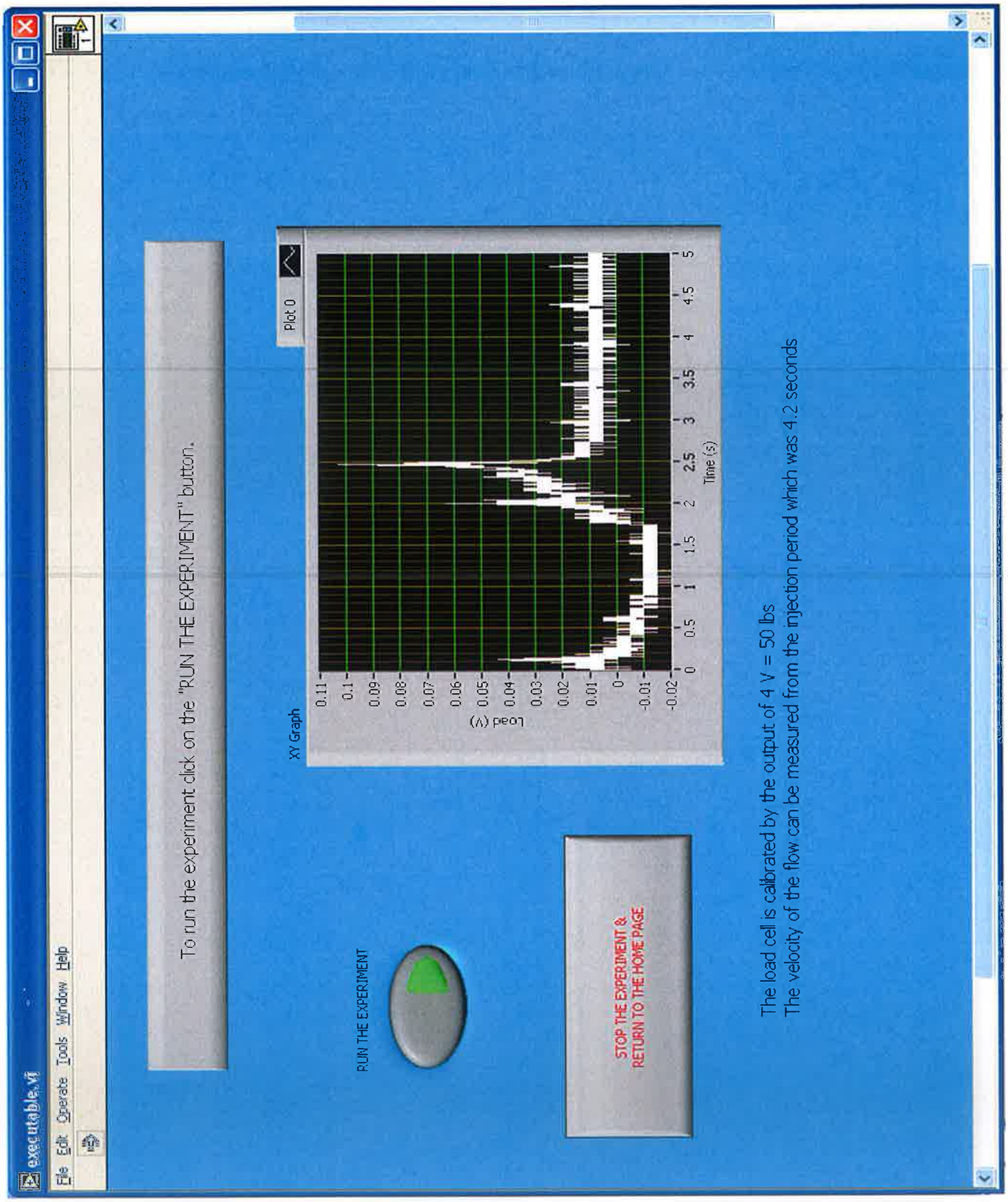

Figure 2.30 Data logging screen for capillary viscometer experiment

2.9.3 Theory and Report Requirements section

Section three contained the explanation and instruction required for the students to process the data collected during the experiment. As the experiment was available to download students could re-run the injection process with sample data and use this example to process their own data. The first screen of section three included explanations on the calculations involved, see figure 2.31, whilst the second and third screens allowed the students to check if they had gotten the correct results from the theory. Students still had to show their own calculations in the report that they handed up as explained in the last screen of the VI. Further screen shots for this VI are shown in Appendix A.

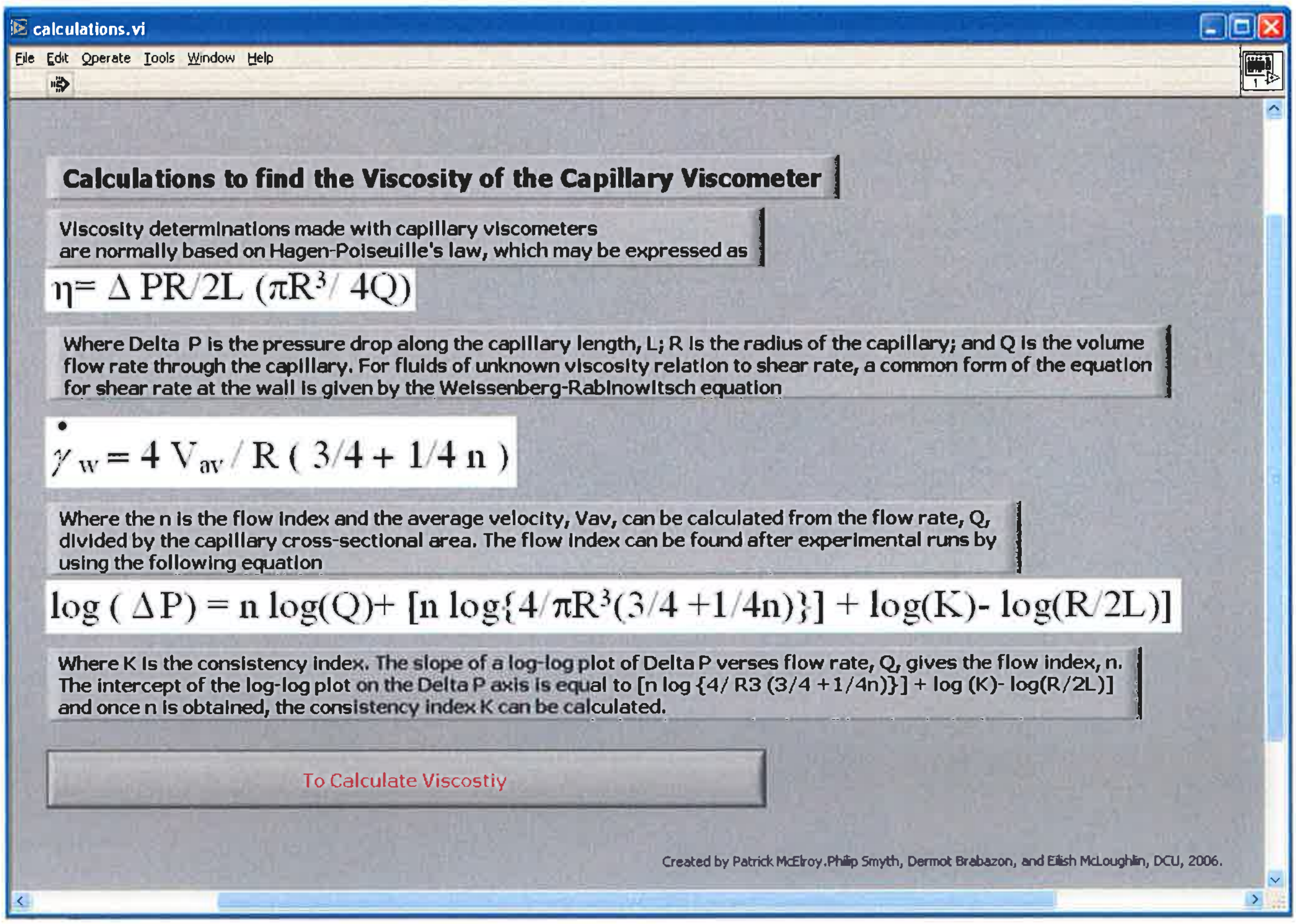

Figure 2.31 Calculation theory screen for capillary viscometer

Chapter 3 Results

This chapter contains the results for all of the analysis carried out during the study. Each students report marks, their multiple choice marks and their questionnaire answers for each individual experiment are reported on.

3.1 Report Results

This section contains the average report marks for each of the instrumented experiments. The total average mark of all the students who undertook the instrumented version is compared to the total average mark of the students who did the non instrumented version. The flywheel, compound pendulum and centrifugal force experiments were all run in the same laboratory module with an instrumented and non instrumented version of each apparatus present in each session. The load cell and LVDT/accelerometer experiments were run for a different module in a similar way. The comparison of student's results for the capillary viscometer experiment is drawn from different years. For this experiment, the results from classes from two years of the instrumented laboratory module were compared to the results from one year of online operation of the instrumented laboratory version and also to the results from two years of related traditional report type continuous assessment. Students' reports were graded using the same marking scheme whether they did the instrumented or non instrumented version of the experiment. This marking scheme was given to students in both the VI and in the laboratory manual provided and can be seen in figure A.6 in appendix one. In this scheme, 30% was awarded for the basic structure of the report, 30% was awarded for the results recorded during the experiment, 30% was awarded for their discussion and conclusions and 10% was awarded for presentation. Reports were corrected by either postgraduate students or by the lecturer in charge of running the laboratory. Whilst correcting the reports the examiners were not aware of whether the student had done the instrumented or non instrumented version of the experiment to ensure a non biased set of results. These results are shown in Figures 3.1 through 3.7.

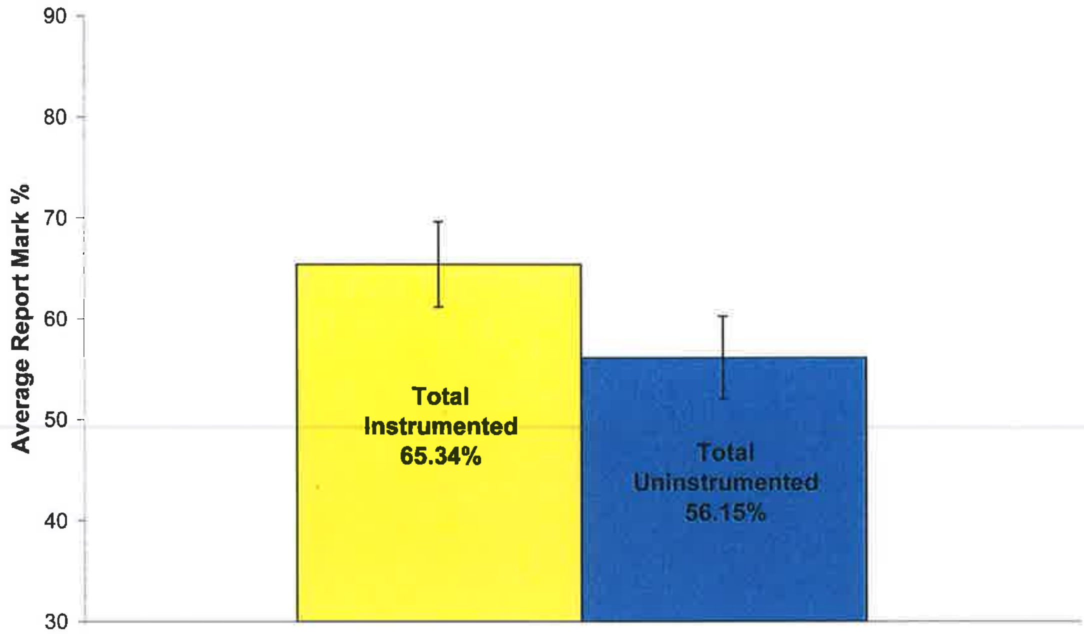

Figure 3.1 Average report marks for students undertaking the Flywheel experiment.
(85 students Instrumented, 84 students uninstrumented)

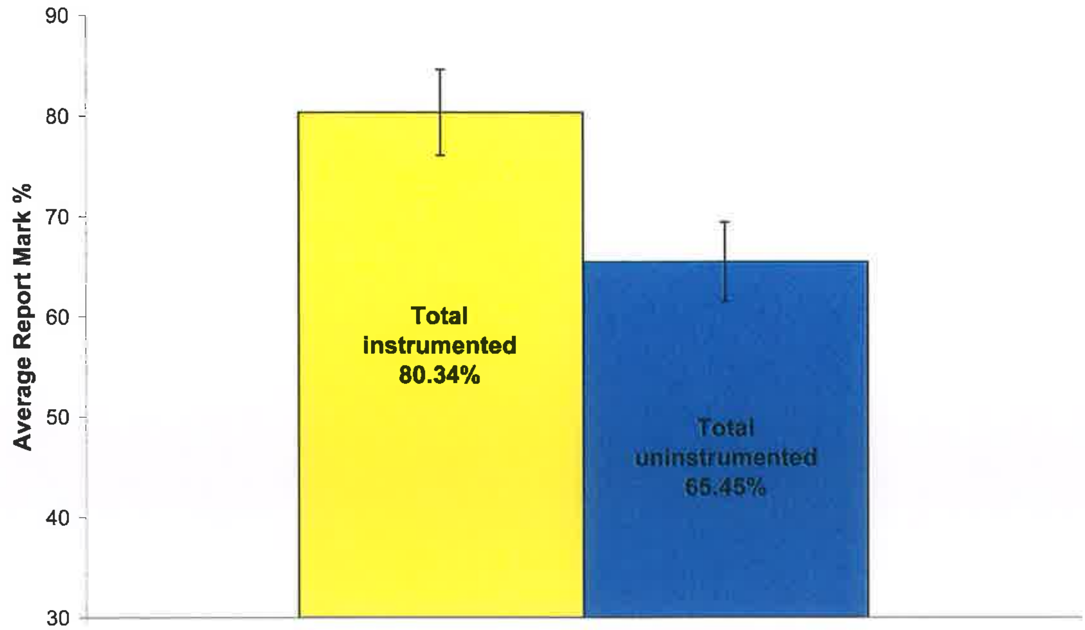

Figure 3.2 Average report marks for the Compound Pendulum experiment.
(78 students instrumented, 79 students uninstrumented)

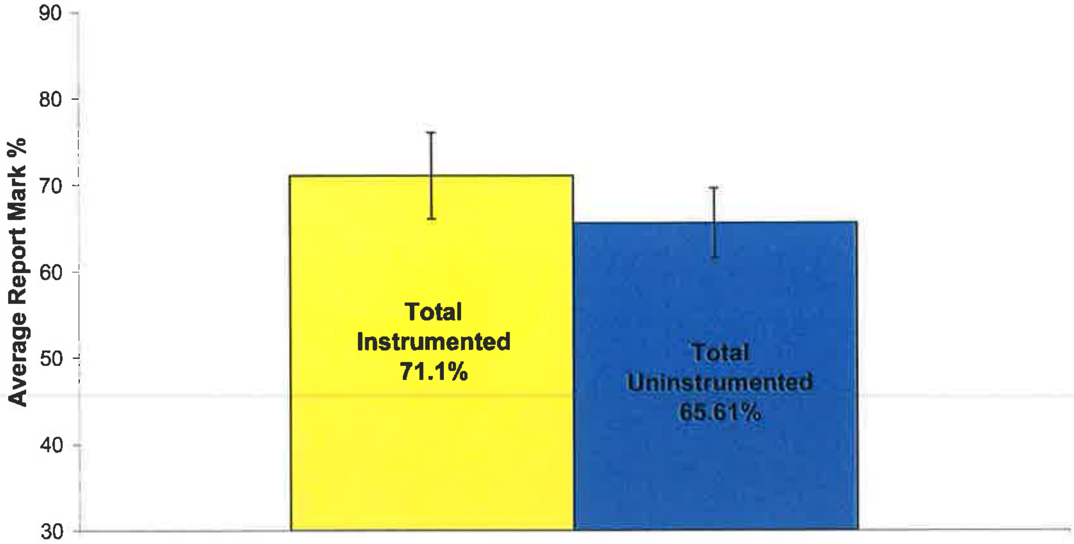

Figure 3.3 Average report marks for students undertaking the Centrifugal Force experiment.
(30 students instrumented, 30 students uninstrumented)

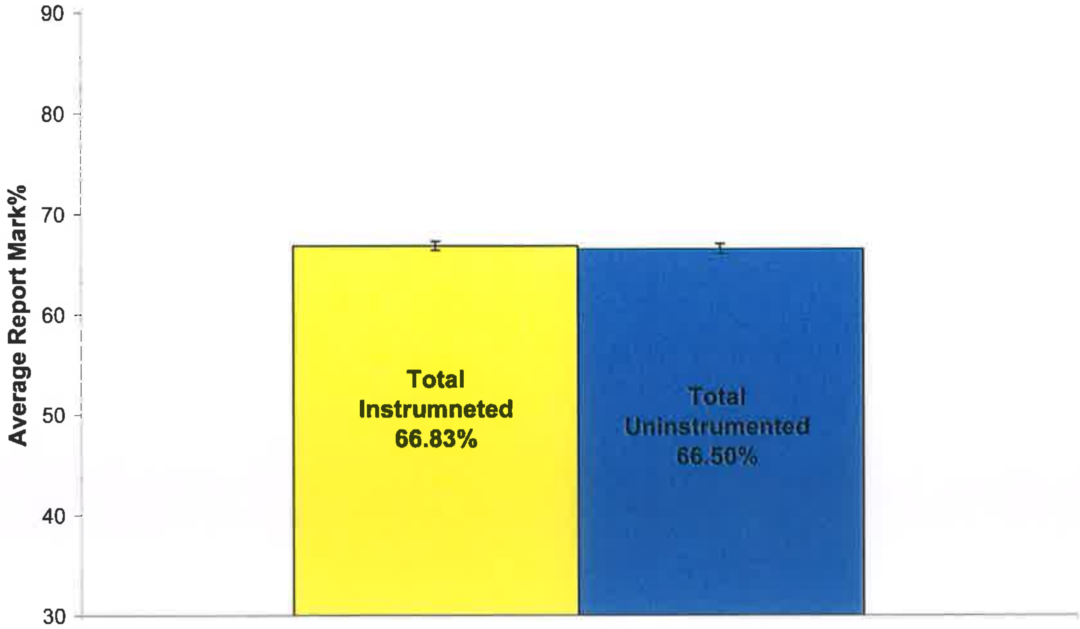

Figure 3.4 Average report marks for students undertaking the Load Cell experiment.
(42 students instrumented, 43 students uninstrumented)

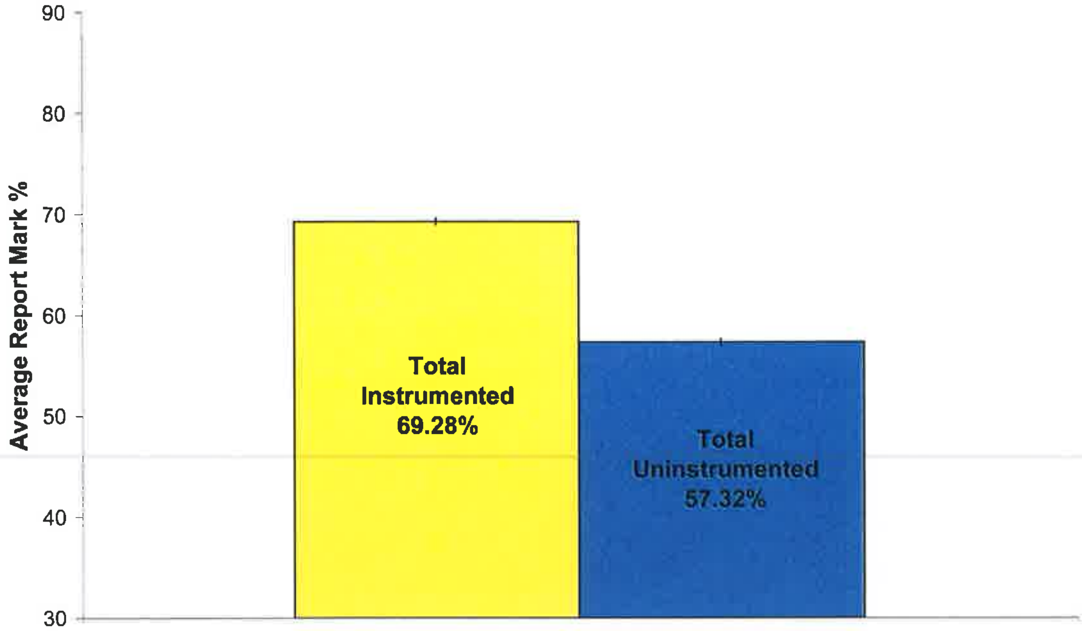

Figure 3.5 Average report marks for the LVDT/accelerometer experiment.
(41 students instrumented, 40 students uninstrumented)

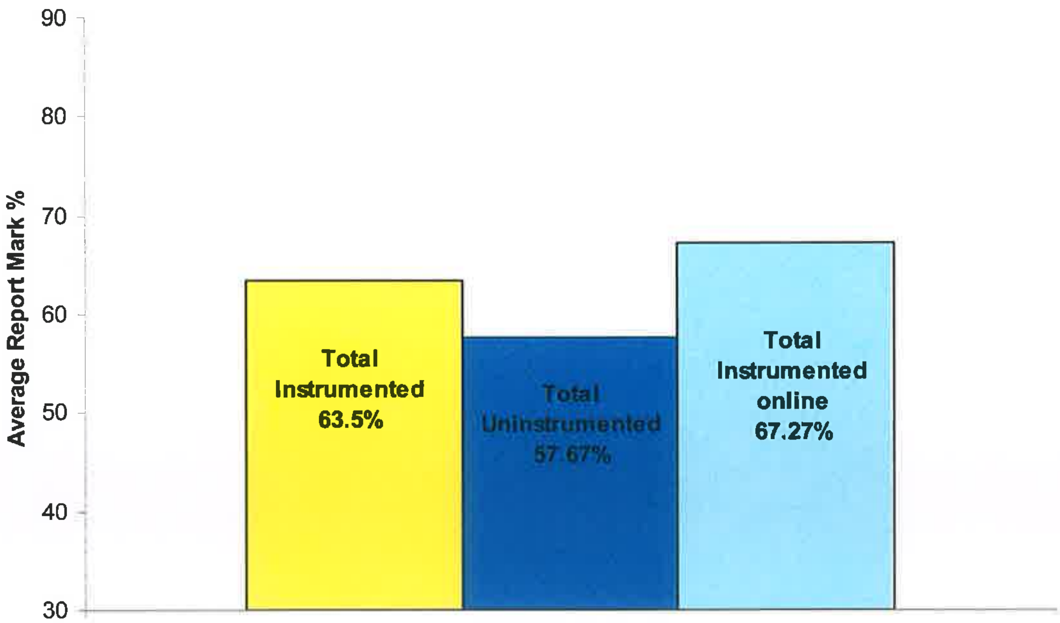

Figure 3.6 Average report marks for the Capillary Viscometer experiment.
(22 students instrumented, 39 students uninstrumented, 15 online)

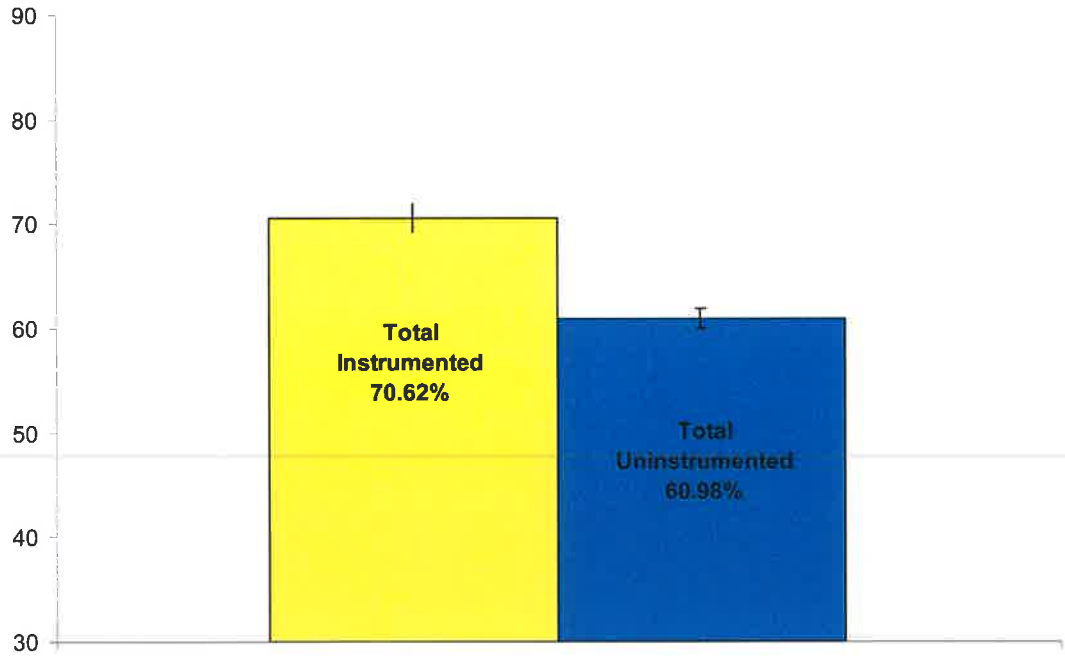

Figure 3.7 Combined total average reports marks for students doing instrumented and non-instrumented experiments.

(298 students instrumented, 275 students uninstrumented)

3.2 Multiple Choice Question Results

This section contains the average marks for the multiple choice questions which were attached at the end of each of the VI's. Each experiment had four multiple choice questions associated with it. Students were also asked to give a reason for the answer they choose. Marks were awarded for the correct answer and for giving a rational reasoning to the problem. As there were four questions asked, each question was worth 25 marks out of a total of 100 marks. Students were awarded 10 marks for correctly answering the question with the remaining 15 going for the quality of their reasoning. As these questions were set at a slightly higher level than that of the experiment a greater level of understanding must be present in order to answer each of the questions correctly. Initially these questions were given to the students as extra work at the end of the lab purely for this study but were later added to both students' answers sheets as well as the VI's, as they proved a valuable instructional tool.

The total average mark of the students who completed the instrumented version of the experiment was compared directly with the total average mark of the students who did the non-instrumented version. This is represented in figures 3.8 – 3.13 which show whether students who had utilised the instrumented version performed better, worse or the same than those doing the non-instrumented version. Multiple choice answers were corrected by a postgraduate student who was not aware of whether the student had done the instrumented or non-instrumented version of the experiment to ensure a non biased set of results. Only the capillary viscometer experiment did not have any multiple choice questions associated with it.

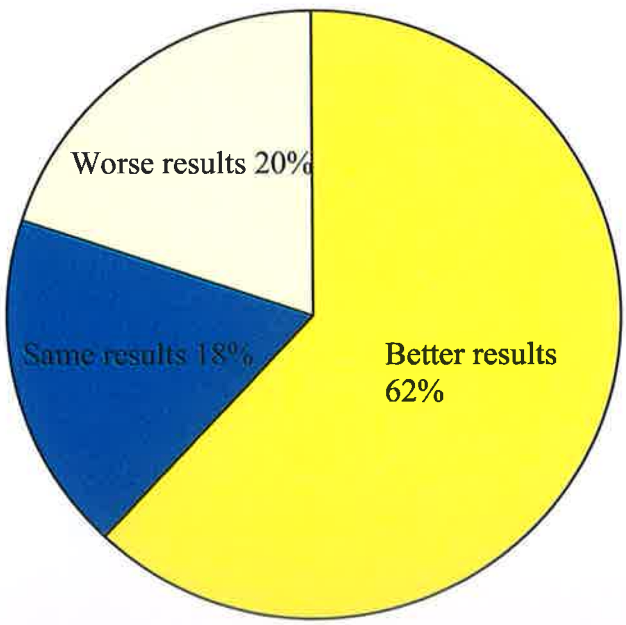

Figure 3.8 Average MCQ performances for students undertaking the instrumented version of the Flywheel experiment, for 100 students total

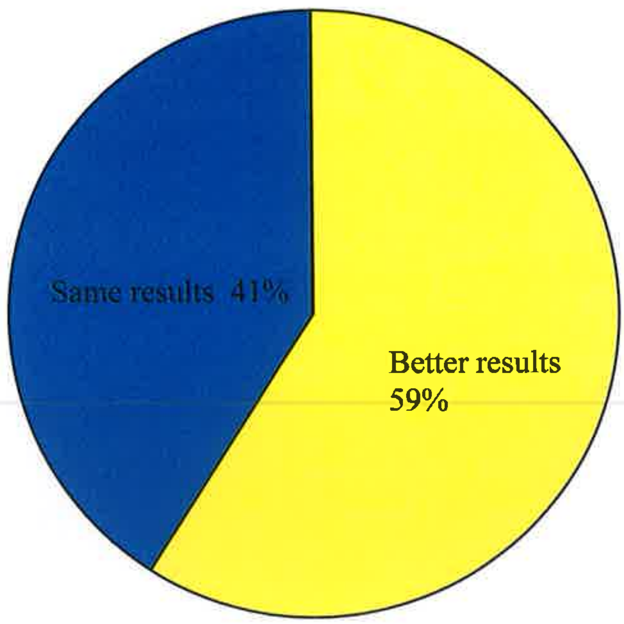

Figure 3.9 Average MCQ performances for students undertaking the instrumented version of the Compound Pendulum experiment, for 96 students total

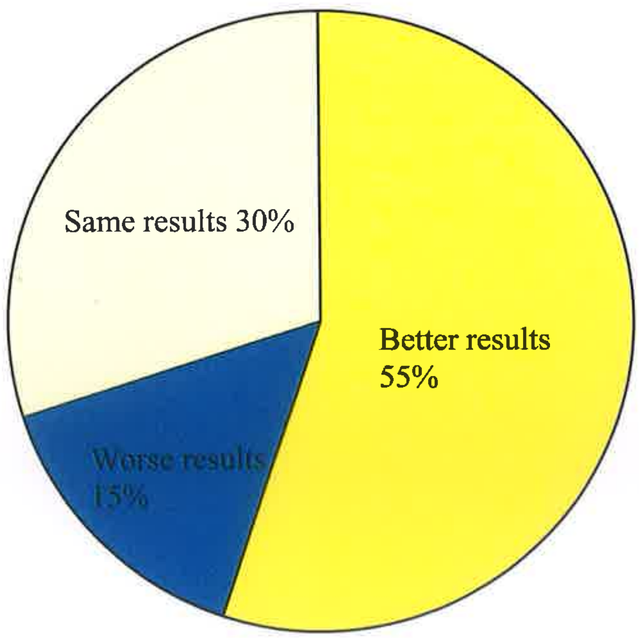

Figure 3.10 Average MCQ performances for students undertaking the instrumented version of the Centrifugal Force experiment, for 60 students total

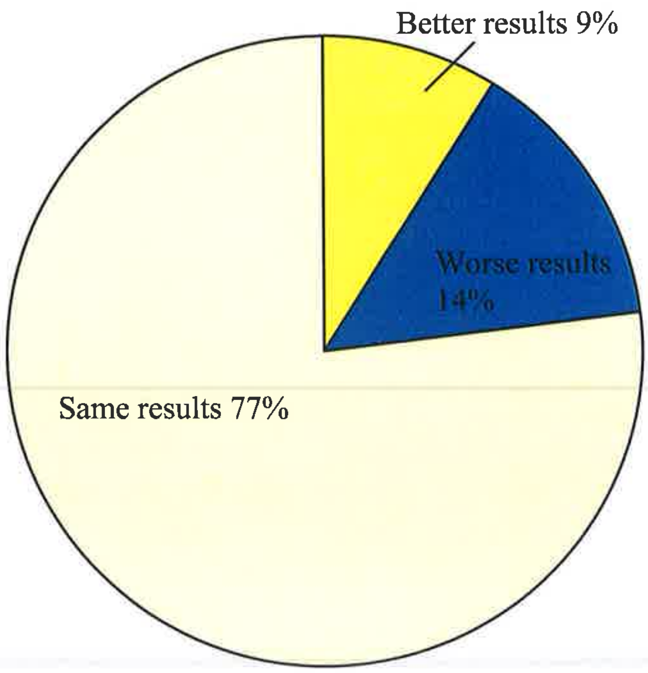

Figure 3.11 Average MCQ performances for students undertaking the instrumented version of the Load Cell experiment, for 85 students total

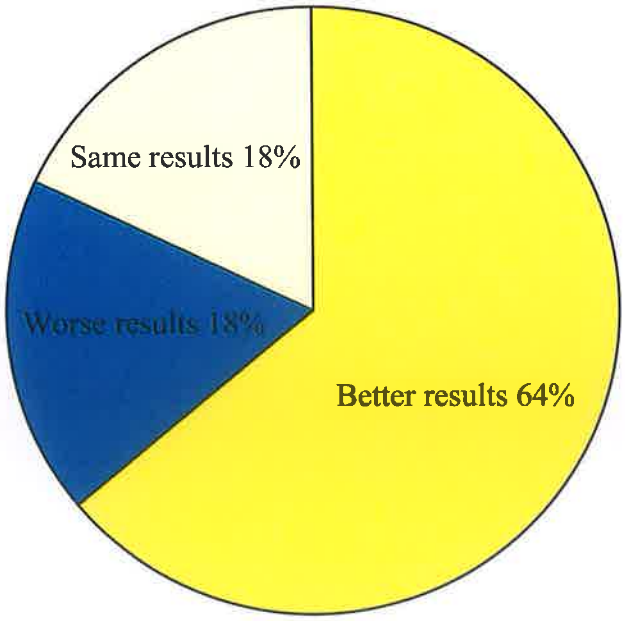

Figure 3.12 Average MCQ performances for students undertaking the instrumented version of the LVDT experiment, for 81 students total.

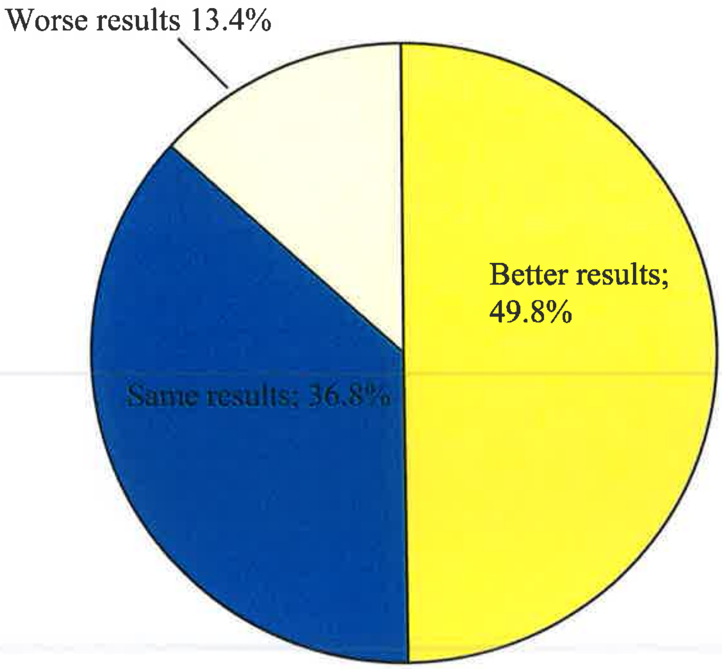

Figure 3.13 Combined total percentages of students using instrumented versions of the experiments performing better, the same or worse than those using the non-instrumented versions, for 483 students total.

3.3Questionnaire Results

This section contains the results of the questionnaires given to students during their first session of their laboratory module and the last session. The questionnaire consisted of 18 questions designed to gauge the students' feelings towards the laboratory sessions they undertook in Dublin City University. The questionnaire was given to all students present and the following results are complied from approximately 350 questionnaire sheets.

3.3.1 Questionnaire Section One

The first ten questions were in regards to the laboratory setup in general and the last eight questions dealt specifically with the virtual instruments. For the first ten questions, students were asked to give a rating as an answer on a scale of one to ten. Answering either one or two represents "extremely poor", between three and five signifies "satisfactory but with short comings", between six and eight corresponds to "good" and either nine or ten denotes “extremely good”. The rest of the remaining questions required either “yes or no” or opinion type answers. These types of questionnaire responses were explained to the students before they answered the questionnaire. Several copies of responded questionnaires had to be discarded as these students did not answer with their opinions but with jokes and creative patterns instead. If there was any doubt whether to discard a questionnaire or not benefit of the doubt was given to the student and the questionnaire was accepted. The responses to each question are presented in figures 3.14 to 3.29. The “before” series in the graph represents the opinions of the students before their first laboratory in a given semester. The “after” series represents the responses of students after their instrumented or non-instrumented laboratory sessions. A copy of this questionnaire can be found in Appendix C.

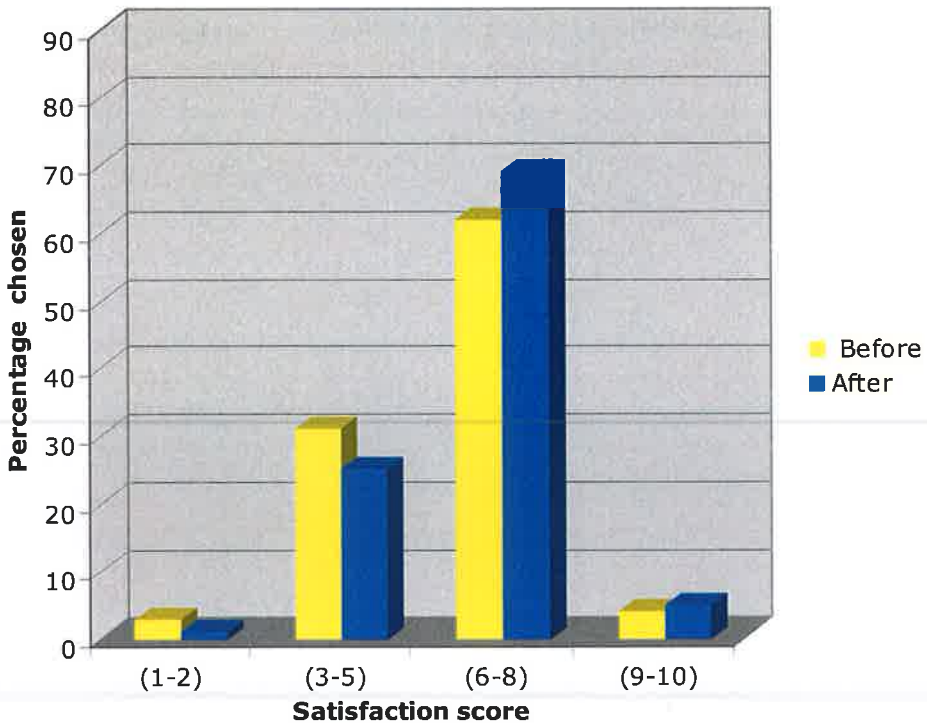

Figure 3.14 Questionnaire Results for "Did you enjoy the lab?"

(1 = extremely poor relation, 10 = extremely good)

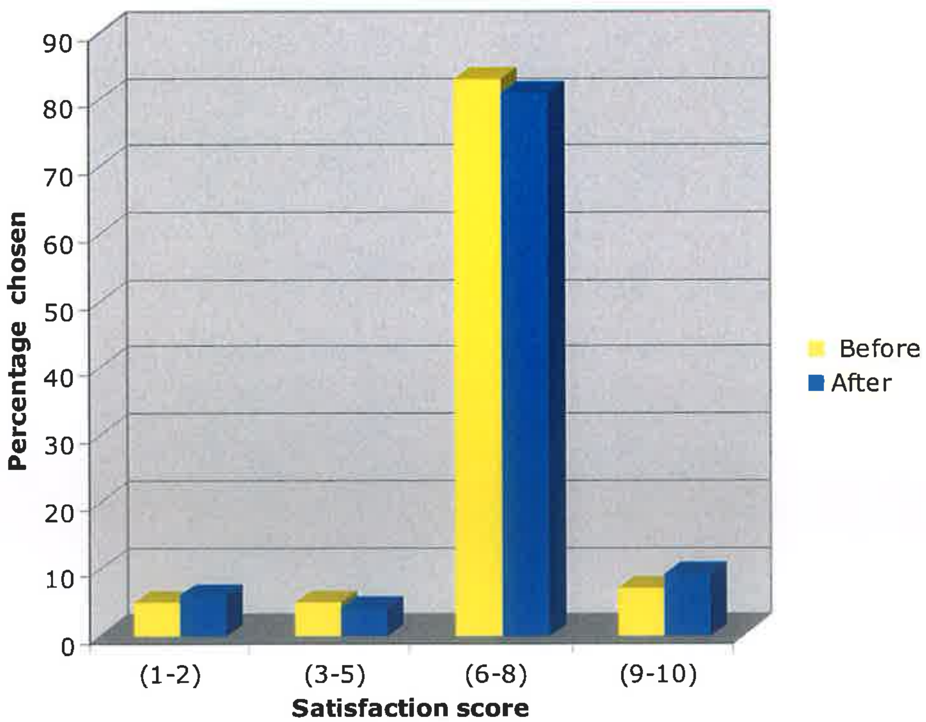

Figure 3.15 Questionnaire Results for "Did you feel you learned from this lab?"
(1 = extremely poor relation, 10 = extremely good)

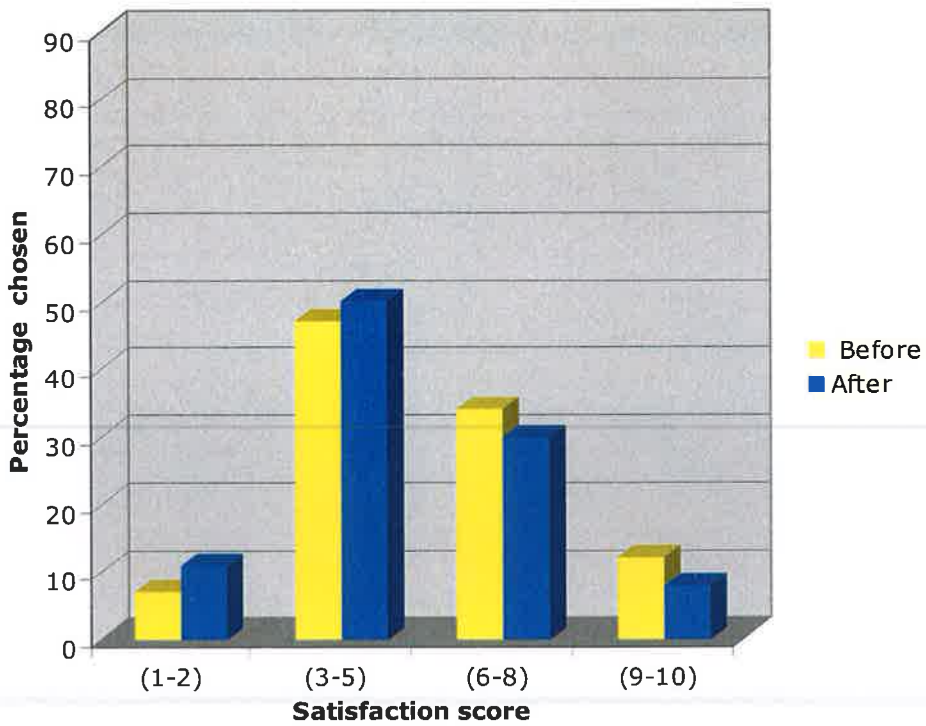

Figure 3.16 Questionnaire Results for "How well did the lab relate to lectures?" (1 = extremely poor relation, 10 = strong relation)

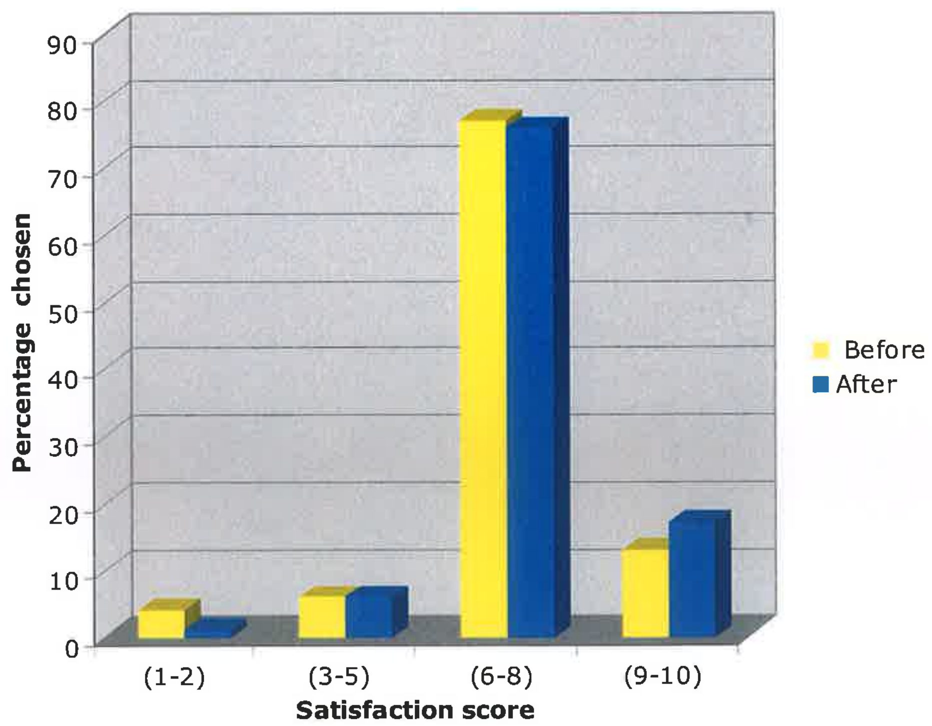

Figure 3.17 Questionnaire Results for "Was the experimental procedure clear and easy to understand?" (1 = unclear, 10 = very clear)

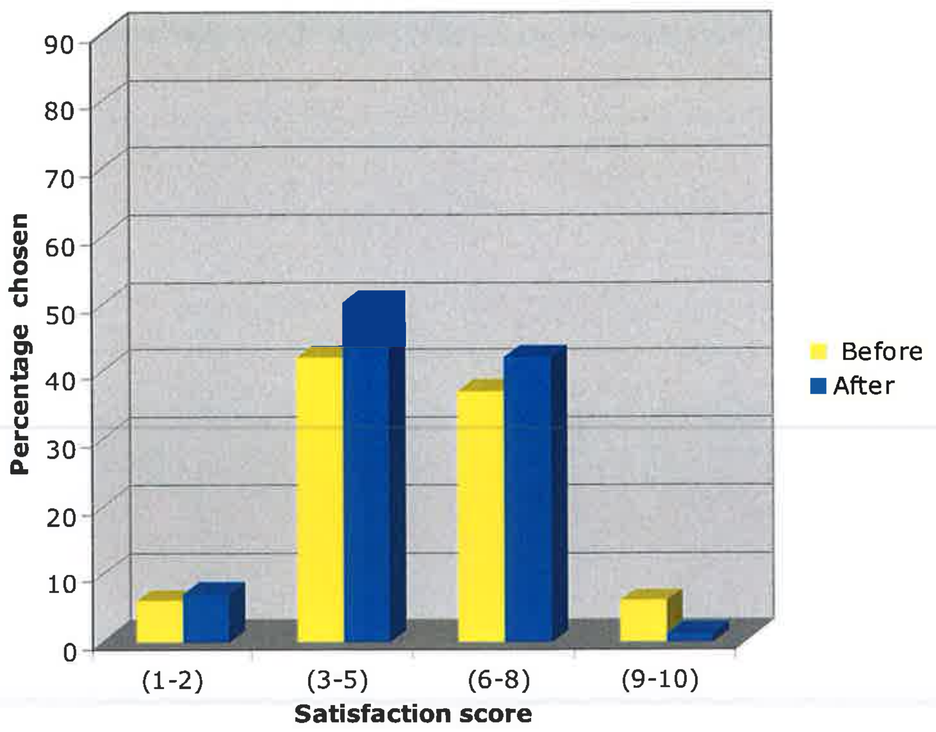

Figure 3.18 Questionnaire Results for "How boring was the lab? (1= most boring, 10=exciting)"

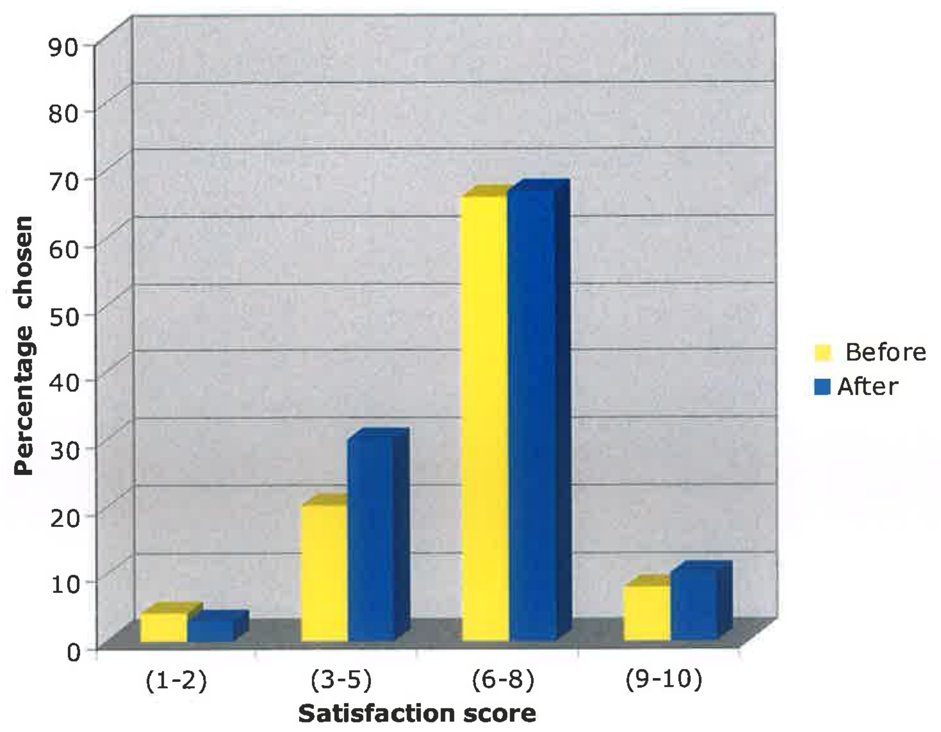

Figure 3.19 Questionnaire Results for "Was the theory to be learned from the lab clear from the lab?" (1 = unclear, 10 = very clear)

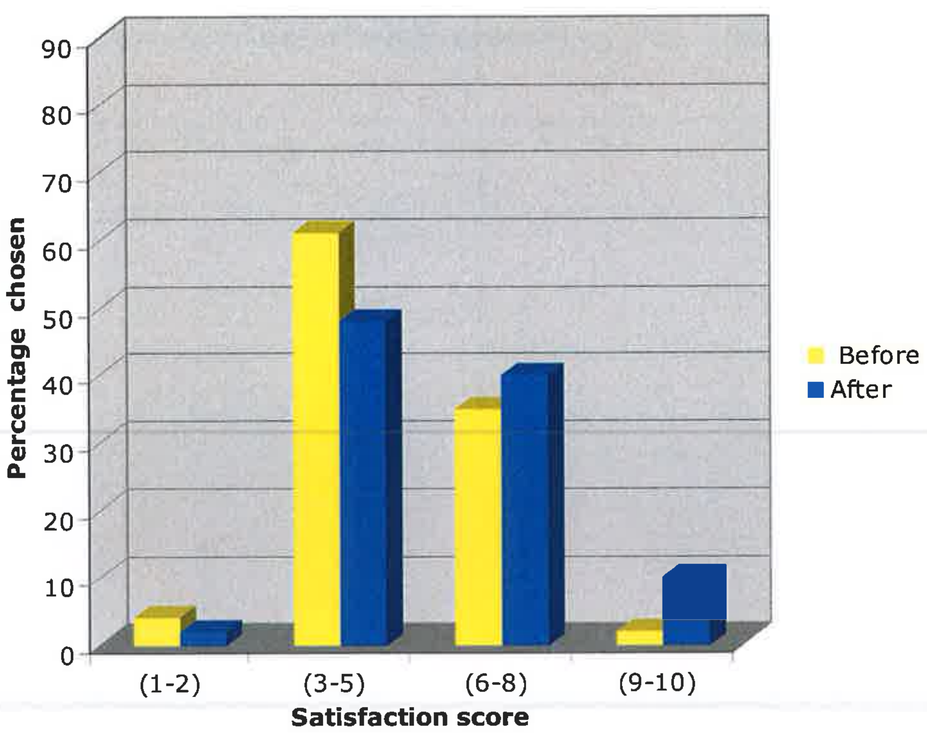

Figure 3.20 Questionnaire Results for "Was the demonstration at the start of the lab adequate?" (1 = unclear, 10 = very clear)

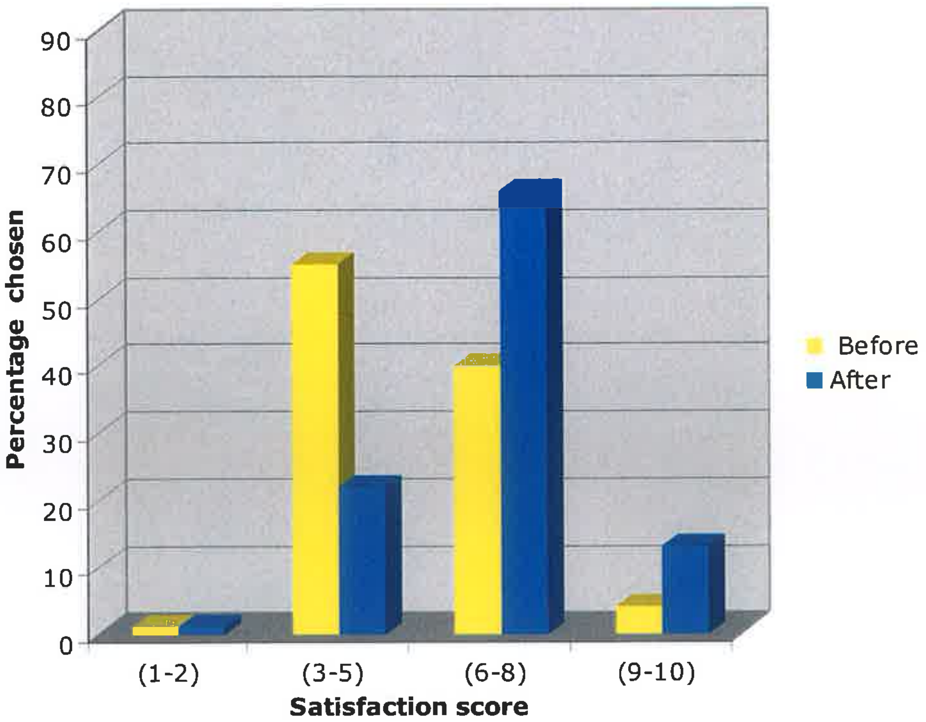

Figure 3.21 Questionnaire Results for "Was the demonstration adequate throughout the lab?" (1 = unclear, 10 = very clear)

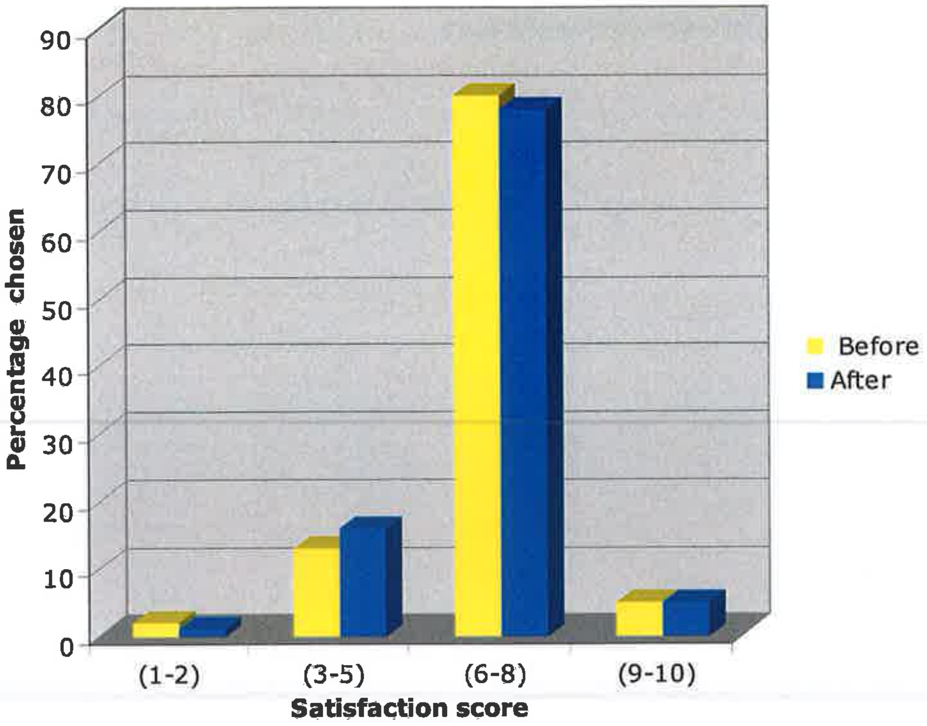

Figure 3.22 Questionnaire Results for "Was the lab beneficial to you in relation to your course?" (1 = extremely poor relation, 10 = extremely good)

3.3.2 Questionnaire Section Two

Section two of the questionnaire relates to the last eight questions asked specifically about the students interaction with the VI's rather than the laboratory in general. The questions in this section were not included the first time that students answered the questionnaire as they had not had the opportunity to operate any of the instrumented experiments.

Relevant opinion answers for questions 14 and 15 are discussed in chapter 4. The answers to this questionnaire are presented in the same sequence as on the questionnaire itself.

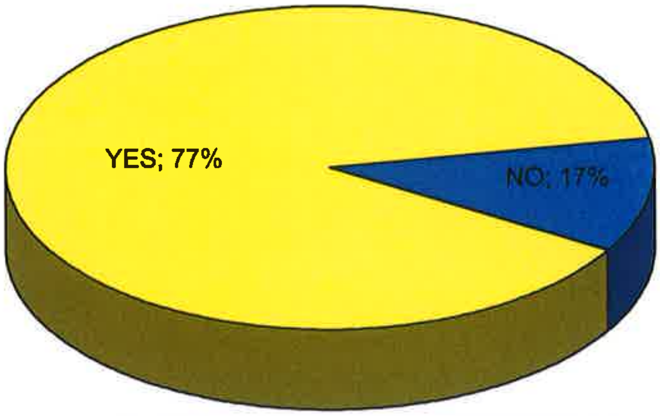

Figure 3.23 Questionnaire Results for "Where any of the lab experiments you did instrumented?"

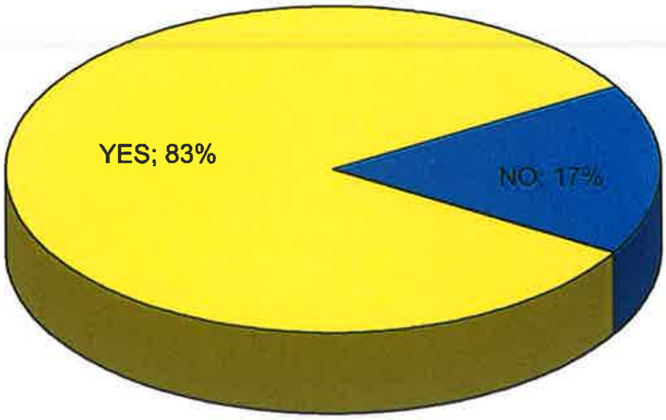

Figure 3.24 Questionnaire Results for "If yes, do you think the VI benefited you?"

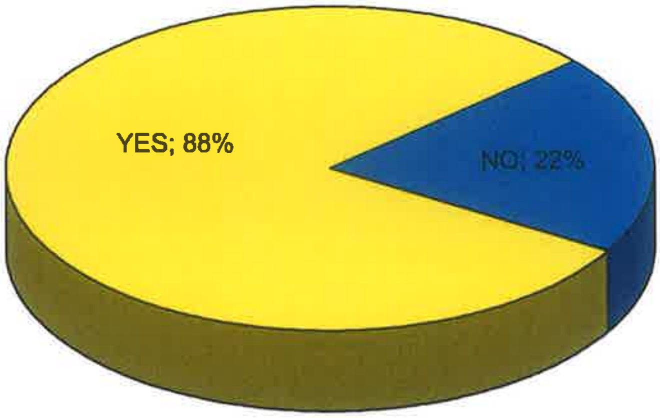

Figure 3.25 Questionnaire Results for "If no, do you think the VI would have benefited you?"

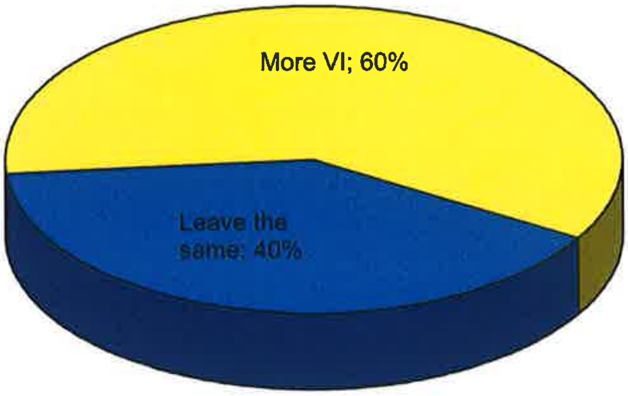

Figure 3.26 Questionnaire Results for "Should the labs be left as previous or should more VI be introduced?"

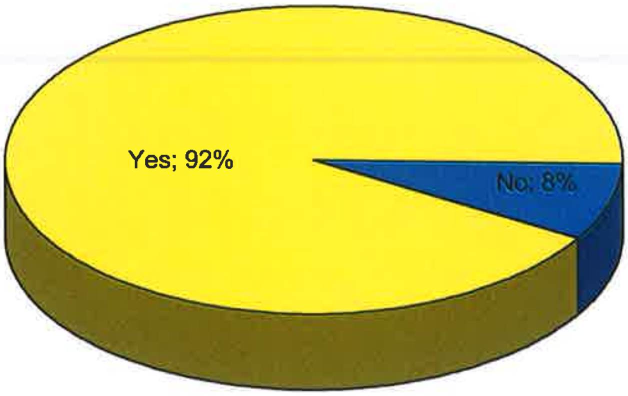

Figure 3.27 Questionnaire Results for "Is using a computer to learn and aid in the laboratory better than having to rely on the demonstrator for help?"

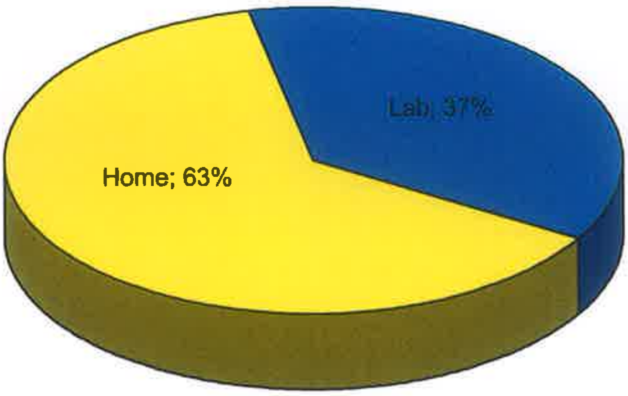

Figure 3.28 Questionnaire Results for "Do you prefer to write up your report in labs or at home?"

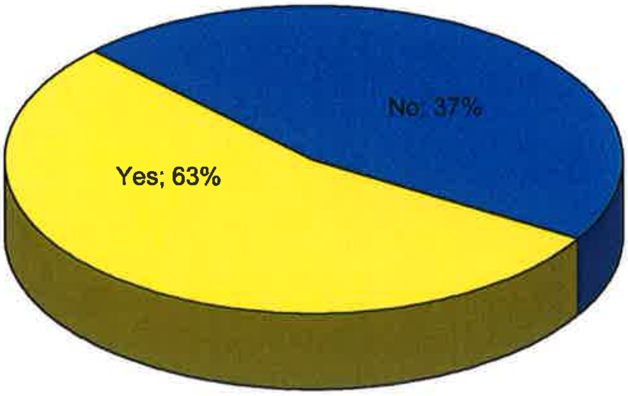

Figure 3.29 Questionnaire Results for "Would you prefer to have access to an online version of the experiment to reference once you have completed the lab?"

3.4 Heart rate Monitors

During the early stages of this study, may laboratories were run with the students wearing heart rate monitors and being videoed as they performed their laboratory experiments. Students would wear a sensing strap around their chest that would record and transmit heart rate data to a wrist watch. The rate data was then be downloaded from the watch at a later date and plotted against time. Students were video recorded as they undertook the experiment to ensure that the relevant peaks of their heart rate were a direct result of being excited or interested in the experiment rather than being stressed or excited for other reasons. This method of analysis was not implemented for all of the laboratory sessions as it was taking a huge amount of time to correlate the video data with the heart rate data. During one laboratory module of 40 students or so, the heat rate of one of the students is shown in figure 3.30. This was correlated with video evidence which showed the student becoming excited whilst performing interacting with the computer and VI during the three sections of the experiment. These are indicted by the marked sections, A, B, and C in figure 3.30. No heart rate profiles showing students being overtly stressed were found.

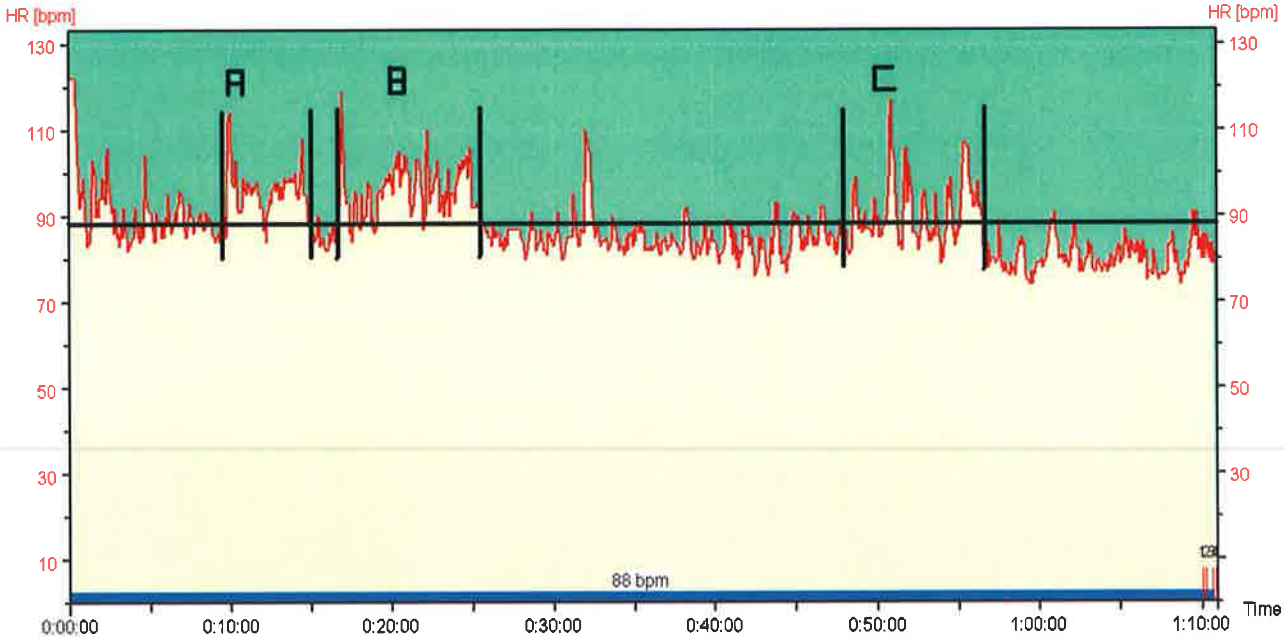

Figure 3.30 Heart rate profile of one student using a VI in lab

4. Discussion and Conclusions

In this section an analysis of each of the separate methods of assessment of students is presented. Each method will be dealt with individually and discussed in relation to all of the experiments instrumented.

4.1 Introduction

The goals of this study were to improve the learning experience for students, the teaching experience for demonstrators, to update the laboratories to allow an understanding of industrial instrumentation and to analyse the effectiveness of all new implementations. Students were surveyed early on by both written and oral surveys. The oral question and answer session was conducted during their laboratory session and consisted solely of what students thought was good and bad about the laboratories before they were instrumented. Responses to the oral question and answer session with the highest frequency are shown in Table 4.1.

Cons		Pros
Labs are too repetitive		Learn team skills
Don't understand what's going on		Tried and trusted method
Boring Sessions		Practical experience
Worried about having a bad partner		Some topics are interesting

Table 4.1 Most frequent responses given by students when asked what they thought of the laboratory sessions before they were instrumented

Some students felt that their laboratory experience would be the same no matter what experiment they were assigned to do. They were of the opinion that the session would consist of them entering the class, seeing what measurements had to be taken, recording their data, plotting a graph and then going home. Some students felt no attachment to their work and had no clue what they were really supposed to be doing. When asked why this was the case students answered most commonly that they did not understand what was going on and that they did not get much more information out of the demonstrators in the laboratory in terms of explaining things in very simple language. Students who enter the various engineering classes have varying levels of ability and also have taken different classes previously. This means that any introduction given must cater for all levels of student and not just those of a higher level of ability. Laboratory groups would generally consist of between three and five students. Students admitted that it was much easier to let the stronger student do the experiment while they helped and copied the results. Some students felt little motivation to become more strongly engaged with their laboratory and this may be down to fact they found it quite boring. It was reported that they sometimes found it difficult to do sections of the experiment due to lack of understanding and hence found the questions difficult.

Students also felt that if they were unfortunate to be paired with weaker students as their report results would suffer because of it. Conversely students remarked that they felt working together in a group helped them develop team skills. For many it is one of the first times they get to work in a project based group working environment similar to what they would have in industry. Students were of the opinion that the laboratory sessions were a tried and trusted method of instruction that has been in place for a long time and therefore must be of benefit to them. This trust in the system was a motivating factor in students attending and finishing their reports along with the credits awarded for the module. For a lot of students this is also the very first time that they get to handle the apparatus themselves rather than having a teacher demonstrate it for them as may have been the case in secondary school. Being able to physically touch the experiment and play around with it is crucial to the learning experience and can be exciting for students not placed in this situation before. If the experiment is exciting and new then it is likely that the students will be more interested in the project and are likely to be more self motivated in completing their assignments. Students were again surveyed but in the form of an answer sheet that was given to them again at the end of their time in the laboratory to see if their opinions had changed once they had used one of the VI. Results from these questionnaires are discussed in section 4.4.

Demonstrators were also asked what they felt was wrong with the laboratory setup. Many replied saying that they are a lot of students to get to and that they cannot give each of them a lot of attention. They also were reluctant to jump in and help students who were stuck in a particular part of the experiment to allow the students to figure out the problem for themselves. They believed that this frustrated students but that is was for the students' own good that they did not get "spoon fed". This study analysed the effectiveness of implementation of virtual instruments into the laboratory by looking at student report marks, MCQ marks, heart rate profiles and student opinion through their questionnaire answers.

4.2 Students Reports

In order to complete their laboratory module, students had to compile a report on each of the experiments they had undertaken. This report is generally completed after the session had ended and is handed up to the demonstrator at the commencement of the next session. Each experiment has a list of requirements in order to achieve full marks and these were given to all students regardless of whether they are doing the instrumented or non instrumented version. Students reports were corrected by either a postgraduate student or by a lecturer, depending on the laboratory. The corrector was unaware of whether the student whose report they were correcting completed the experiment on an instrumented piece of apparatus or not. The aim of this work was to design virtual experiments for engineering laboratories, to use them to interest the students and to enable them to more easily understand the concepts being taught to them. Students armed with this greater understanding would then be able to gain higher marks in their reports.

The total average reports marks for each of the individual experiments can be seen in section 3.1. The six instrumented experiments examined showed better results for students undertaking the instrumented version as opposed to the original setup. The load cell experiment showed students gaining very similar marks for either the instrumented or non instrumented version. The load cell experiment was demonstrated by one particular technician in every laboratory session. This technician gave a high level of attention and instruction to both sets of students doing the experiment per session and is seen as the reason why students doing the non-instrumented version did as well in their reports as the students using the instrumented version. The non-instrumented and instrumented students cannot be used as control groups for this study as the demonstrator showed both groups the VI, without realising the impact on this study. This LVDT experiment was run at exactly the same time, in exactly the same room, with exactly the same group of students only minus the full time demonstration. This experiment was demonstrated along with other experiments by a postgraduate student. Students attempting the instrumented LVDT in the same laboratory scored on average a full grade higher on their reports than students attempting the non-instrumented version (see figure 3.5). It is important to look at why students are performing better with instrumented experiments. Marks are awarded to students for the basic structure of the report 30%, the results recorded during the experiment 30%, their discussion and conclusions 30% and 10% is awarded for presentation. Students using the instrumented version are given the same information available to the rest of the students but just at different times and in a different format. Students are brought through the experiment by following the VI and this allows them to identify clearly with what similar pattern they should follow in organising their report. It is easier to see the key points to be taken from the experiment and what sections to highlight in their report. Students can also explain these concepts in the same manner in which it is presented to them. Experimental results are also recorded by the computer which allows observation of what is going on during the experiment rather than having to watch a stopwatch or dial. This allows a greater working understanding of the apparatus to be gained and also means that the data is organised and ready to present and use for the calculation sections. Each VI guides the students through the theory part of the experiment. This forces students to examine the physical processes that occur during the experiment rather than just substituting values into equations and calculating an answer without understanding its significance. Students have the ability to return to the explanation screens at anytime to confirm and check their thoughts on what is happening in each experiment. This facilitates shy students who may have a fear of being seen to be stupid by not understand and having the demonstrator to slow down and repeat what was said.

The first five experiments to be instrumented were all part of an undergraduate program while the capillary viscometer is also part of a taught masters program. This experiment showed a similar pattern of instrumented students performing better than others. This experiment was run last year as part of an online laboratory class. Students would perform the experiment on their own computer with sample data already included with the VI. Similar results between the laboratory version and the online version were to be expected as this experiment is run as a demonstration rather than by the students.

Prof. Phil Race of Leeds Metropolitan University, a renowned expert in this field, has recently hypothesized that there are five factors effecting successful learning which should be present in a learning object in order for it to be really efficient and of benefit to students. These five factors are (i) learning by doing, (ii) learning from feedback, (iii) making sense,

(iv) wanting to learn, and (v) needing to learn. Virtual Experiments in DCU now include all five of these components for effective instruction [REF##]. (i) Students learn by doing the experiment itself as there is still a *hands on* aspect to the experiment; (ii) Students learn from the instant feedback given to them from the calculation sections of the experiment and from the real time output from the graphs on screen; (iii) The explanations in the VI relate to real world applications and give the students a reference point to make sense of what they are being taught; (iv) With increased interest levels and interactive experiments students can begin to really enjoy their laboratory experience and want to continue on. (v) Students are told what is needed to complete their reports in order to pass the module and in order to become a graduate engineer. Having these five key factors present in the VI design is believed to be the main contributing factors as to why the total average report mark for instrumented experiments is approximately a grade average higher than that from non-instrumented experiments.

4.3 Multiple Choice Questions

At the end of each experiment, with the exception of the capillary viscometer, each student completed a set of four multiple choice questions. These questions were set at a slightly higher level than that of the experiment to test whether students really understood the concepts being taught to them. Each question asks the student to make a choice on their answer and then to explain why they made this choice. In the marking scheme, 10 marks were awarded for the correct answer and 15 for the quality of their explanation. Students were instructed to answer the MCQ on their own away from other students. From these responses, 49.8% of students who had done the instrumented versions of their experiment performed better in their MCQ, with 86.8% of them performing the same or better than students who did the non-instrumented versions. This clearly shows that students using the

VIs left the laboratory with a much greater understanding of what they were being taught. This is also thought to be due to the VI giving the students an area of focus, pinpointing the important areas of the experiment and then recording the data allowing them to see these concepts in action rather than focusing too much on the dial of an instrument (e.g. stopwatch in pendulum experiment). The figures for the load cell experiment were to be expected due to the same high level of demonstration and explanation particular to this experiment. It is important to note that this trend in results is common to both the first year and fourth year experiments and that just because students have gone through other laboratory sessions before, does not mean that they know what they are doing. This result is also common to the use of CBL with secondary school students found in a study carried out in DCU by Anna Walshe for her Masters thesis [REF]. The students that engaged with scientific process facilitated by the use of appropriate instrumentation had a better understanding of the scientific concepts contained within the Junior Certificate Science syllabus than the students taught using more traditional methods. They showed improved retention of syllabus content and demonstrated a better ability to apply their acquired knowledge to situations outside of the syllabus.

4.4 Questionnaires

4.4.1 Section One

The questionnaire survey is distinct from the oral survey that given to students midway through their first laboratory session. This survey was given to the several classes as a whole at around the same time as the oral survey and given again, with the extra questions relating to the VIs, at the end of their laboratory sessions for the given module. The first ten questions that are common to both sets relate to the laboratories in general and were designed to gauge how students felt about the module as a whole. Each of these ten questions was answered by circling a number on a scale which translated into a graded response. Answering either one or two represented "extremely poor", between three and five signified "satisfactory but with short comings", between six and eight corresponded to "good" and either nine or ten denoted "extremely good". If the question specifically asked about a particular feeling towards the lab, for example boredom, students were instructed to use the same scale selecting one as the lowest value and ten as the highest. When students were given the survey for the second time the same rules applied for section one and section two was made up of either opinion or yes and no answers.

When students were asked if they enjoyed themselves, 8% more students felt that they had enjoyed their labs more once they had completed the VI versions of the experiments. Although this is not a huge percentage, when this figure is taken into consideration amongst the rest of the questions, the effect of the VIs as a whole becomes clearer. Students found their experimental procedure (figure 3.17) and their experimental theory (figure 3.19) much clearer to understand. They found the lab less boring and more exciting (figure 3.18) and crucially found that the demonstration at both the start of the lab and throughout was much more satisfactory (figures 3.20 and 3.21). As expected the students felt that their labs related the same amount to their lectures as none of the actual material used in the VIs was different to that in the traditional laboratory just the manner through which it was presented (figure 3.16). Students still felt the lab was beneficial to them (figure 3.22) and although they did not feel and if they had learned a significant amount more (figure 3.15) it is clear from their report and MCQ results that they actually did, indicating that they felt no extra workload imposed to work with the VIs but rather the opposite.

4.4.2 Section Two

Section two of the questionnaire related to the VIs directly and to students personal opinions on improvement within the laboratory session. This section is of particular interest as it confirms students positive opinions of the VIs employed even if the previous questions did not portray the laboratory as a whole in the same manner. Question 11 was included as a confirmation that a significant number of students had done at least one instrumented experiment, see figure 3.23. This left one quarter of the total number of students left as a control group who did not have any contact with a VI during their module. Of that quarter of students, 88% thought that the VI would have benefited them in the lab. With no contact with the VI it is hard to speculate where these students thought that the VI would have been beneficial to them. That is of course excluding the fact that these students would be able to discuss the merits of the new versions with the 83% of students who did use it and thought it was beneficial to them. It is also interesting to note that 60% of students would increase the number of VIs present in the labs, with 40% leaving it at current levels. These figures would indicate that there is some room for more experiments to be instrumented but that maybe not every experiment needs a full VI. One of the most significant figures to come out of the questionnaire was that 92% of students believed that it would be better to have the backup of the VI rather than having to rely on a demonstrator for help. Having the VI and its reference section available, enables students to become more independent in their experiments which possibly could lead them to much greater experiments operating even more independently. This trend continues through to the final two questions with students preferring to work together in a laboratory but wrote their reports in their own time either at home or in the library. Students felt that they could complete a much tidier complete report when given the time to do so and hopefully be given the VI online to reference as they did it. Four opinions given by students are presented in Appendix C. These opinions are from two students who took instrumented experiments and from two who only took non-instrumented experiments and confirm what previous figures have shown.

4.5 Heart Rate Monitoring

The heart rate profile shown in figure 3.30 is the only correlated data set shown from the assessment made with the heart rate monitors. This data was matched and synchronised with a video file that was recording the student's activities throughout the lab. This particular student was working in a smaller group of three girls with little outside interference to disturb. Other heart rate profiles had to be discarded as too many factors could affect the student giving a false reading. These factors could be how tired they were, if a loud noise had startled them or even who was sitting beside them. The only way to record this data and use it would be to some how figure out a way of quantifying or getting rid of outside influences which would be very difficult in a group laboratory environment.

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Appendix A

A.1.1 Flywheel Experiment

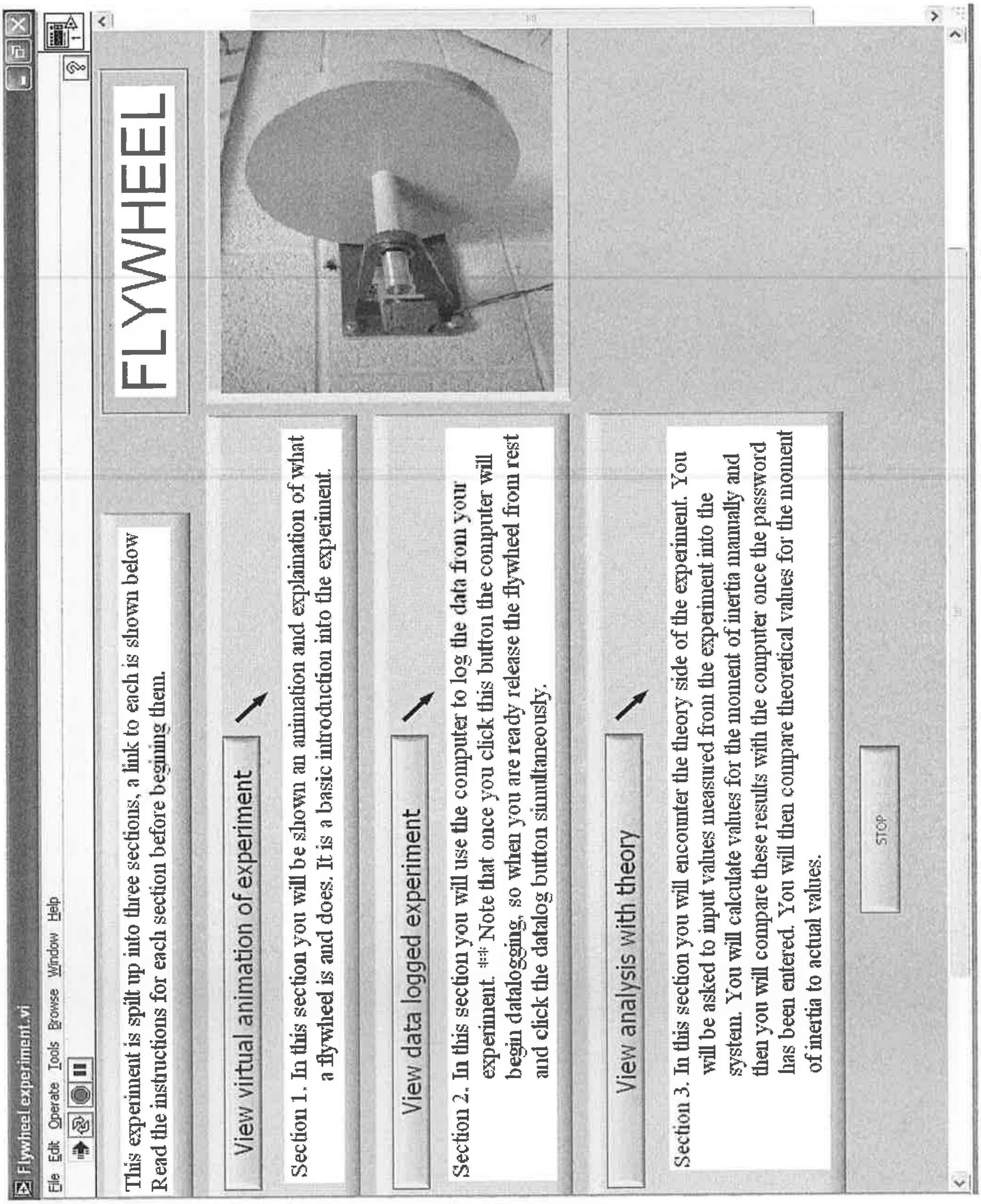


Figure A1.1 Home Screen for Flywheel Experiment

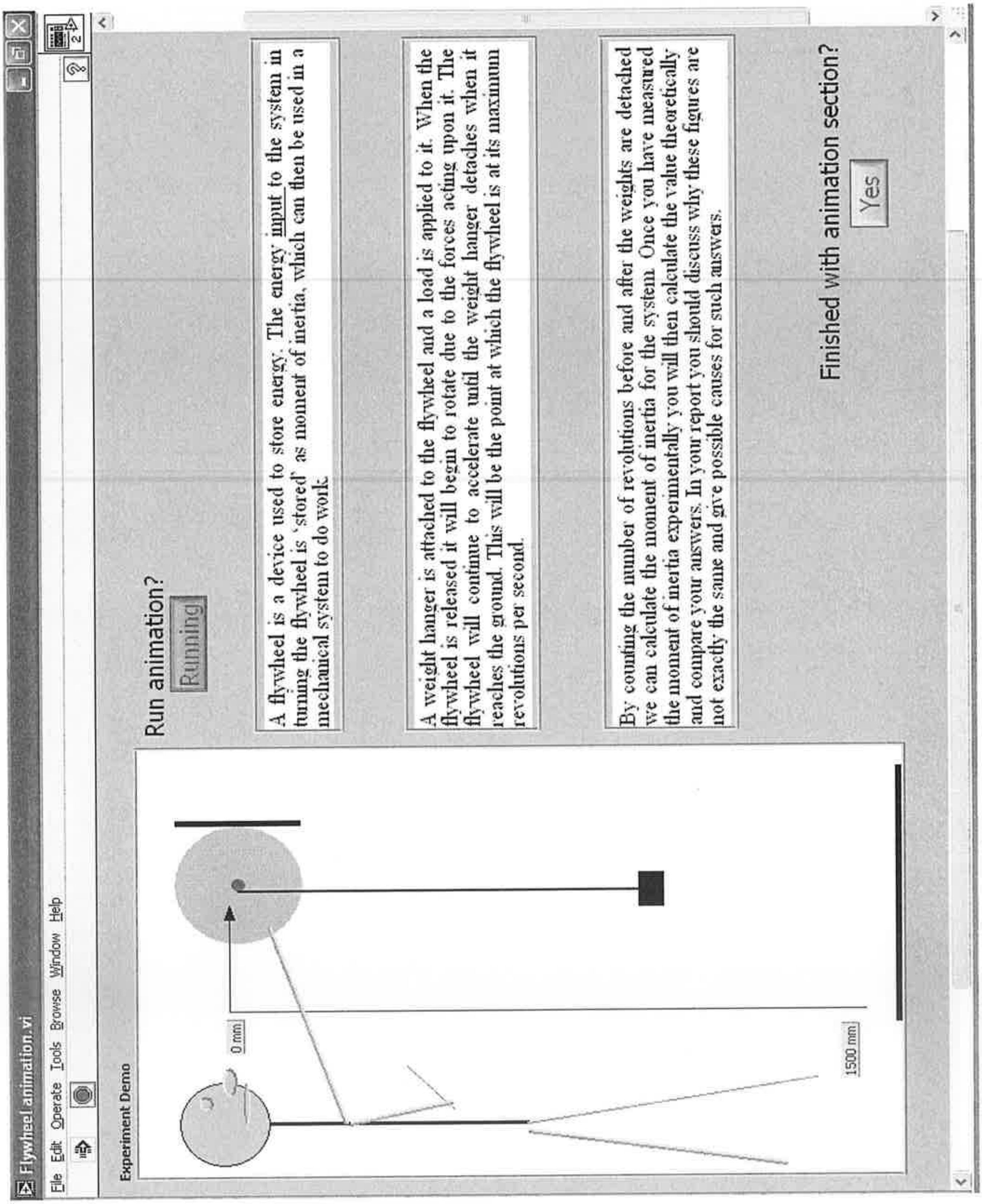


Figure A1.2 Animation Screen for Flywheel Experiment

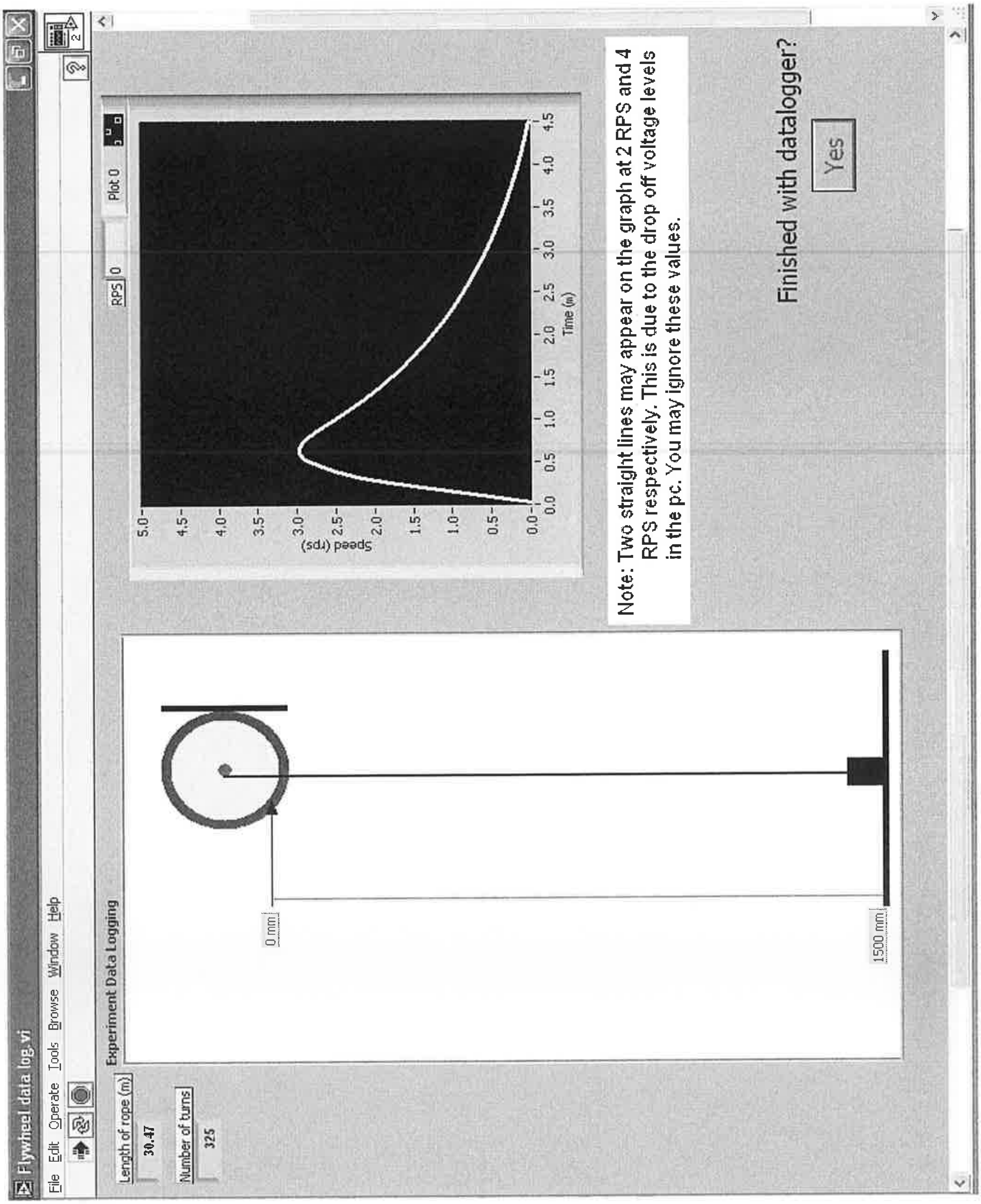


Figure A1.3 Datalogging Screen for Flywheel Experiment

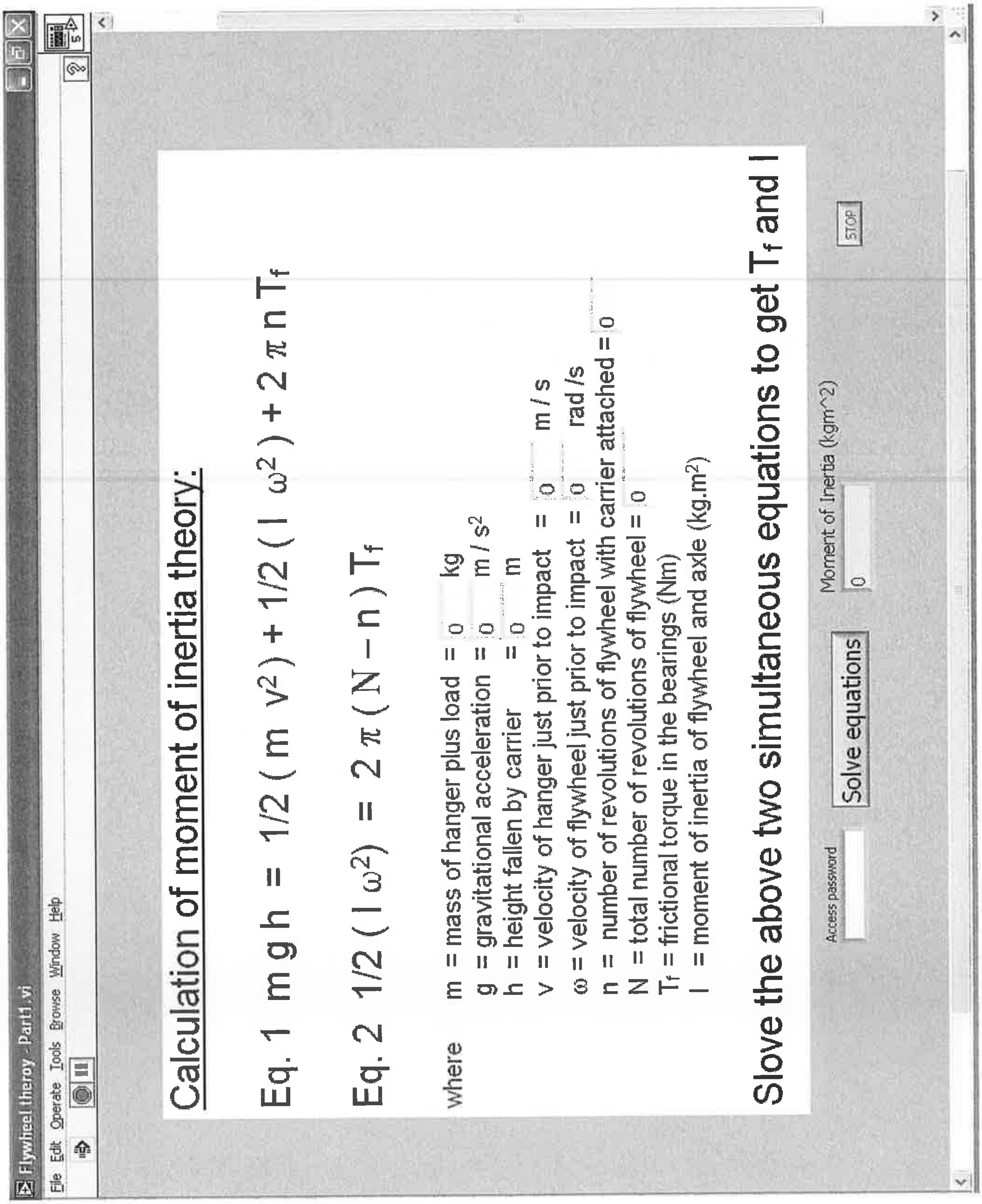


Figure A1.4 Theory and Analysis Screen One for Flywheel Experiment

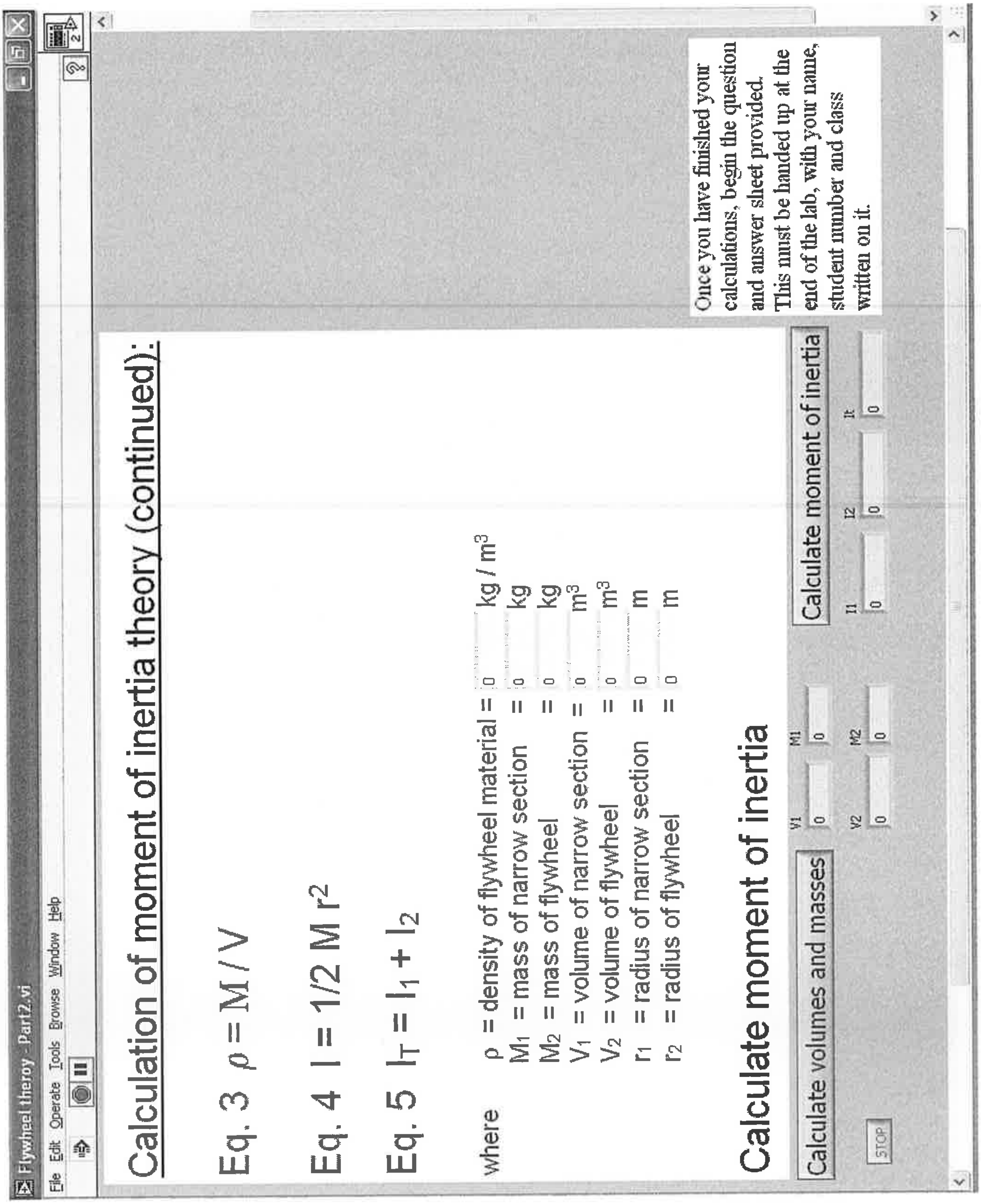


Figure A1.5 Theory and Analysis Screen Two for Flywheel Experiment

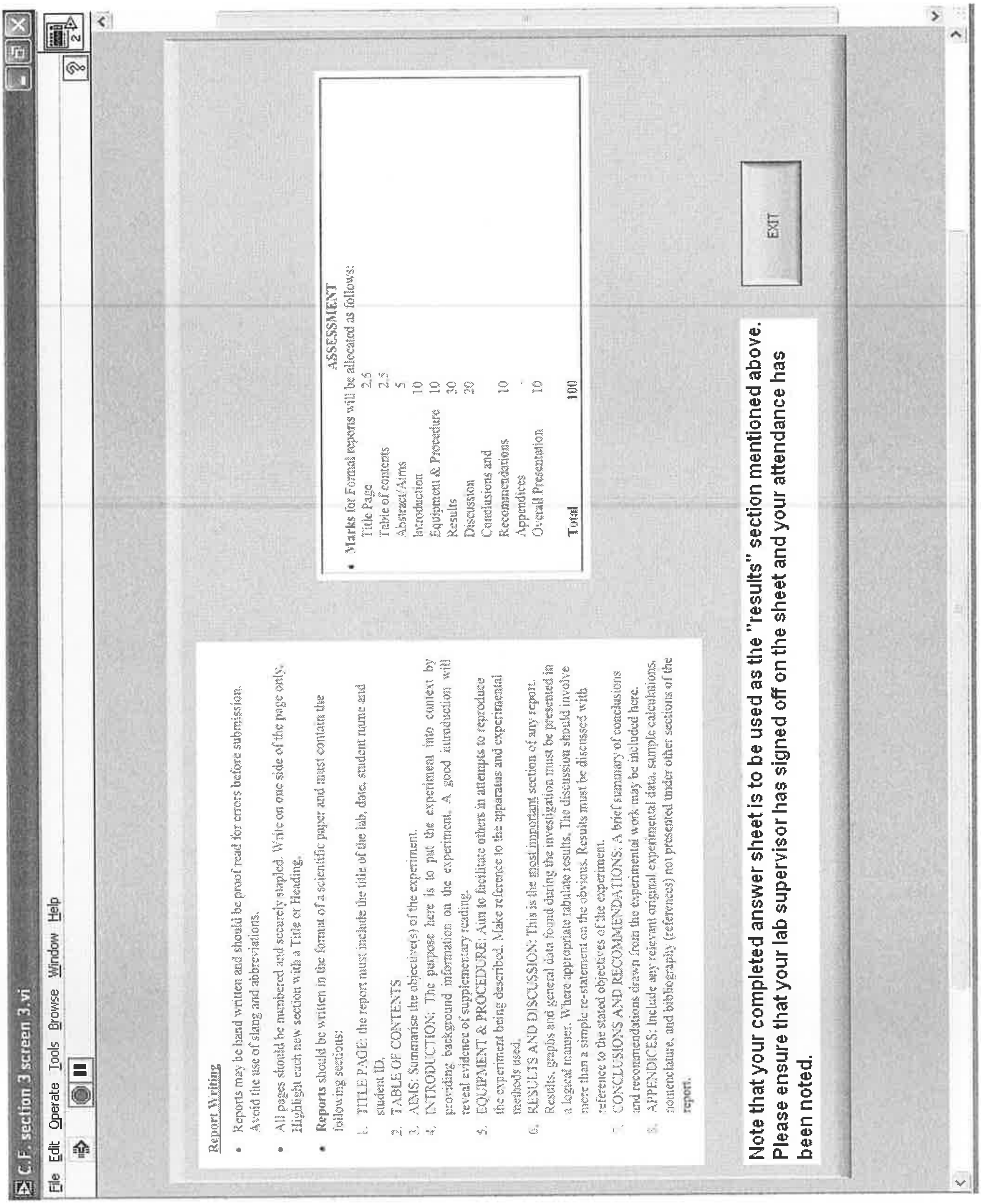
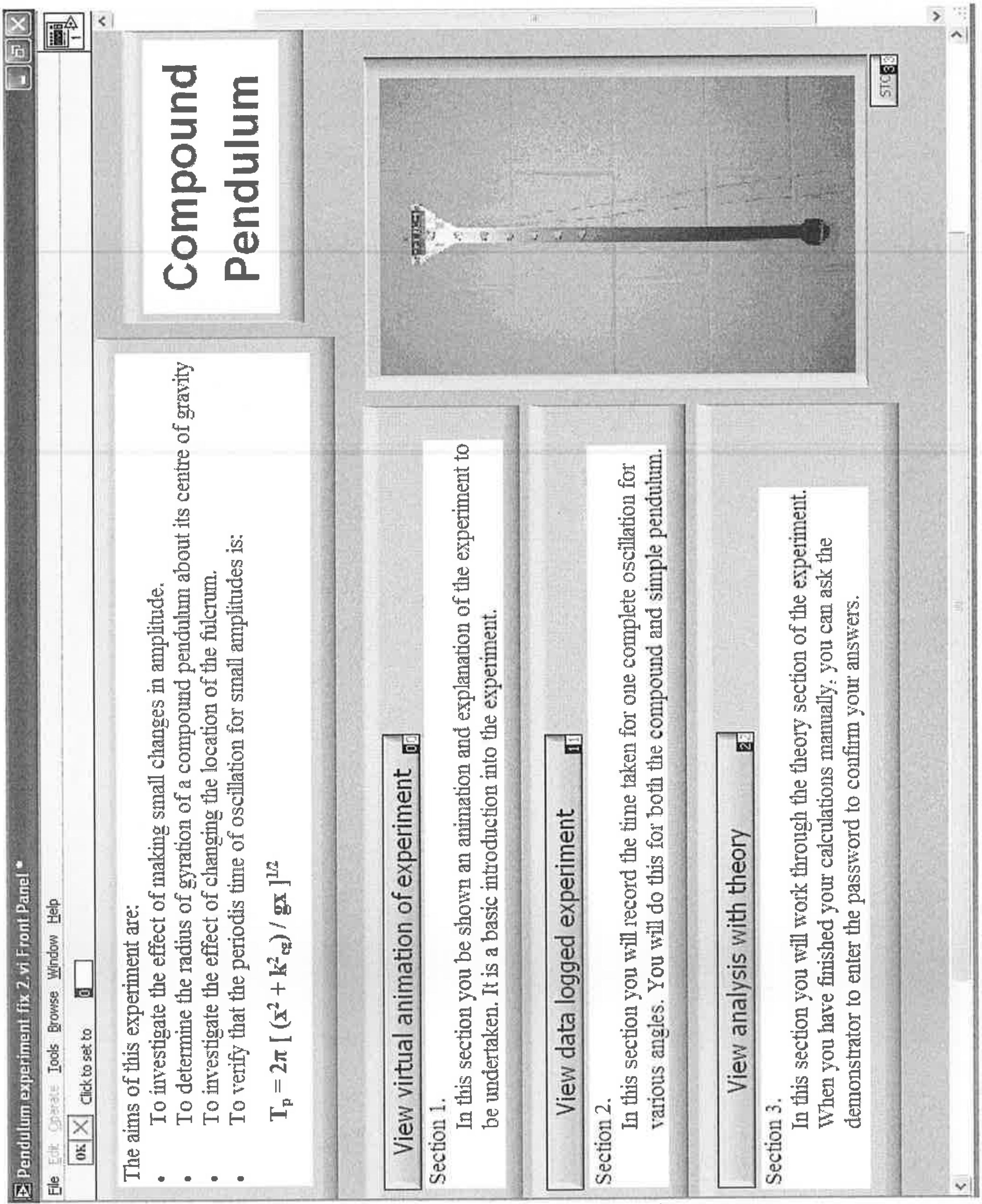
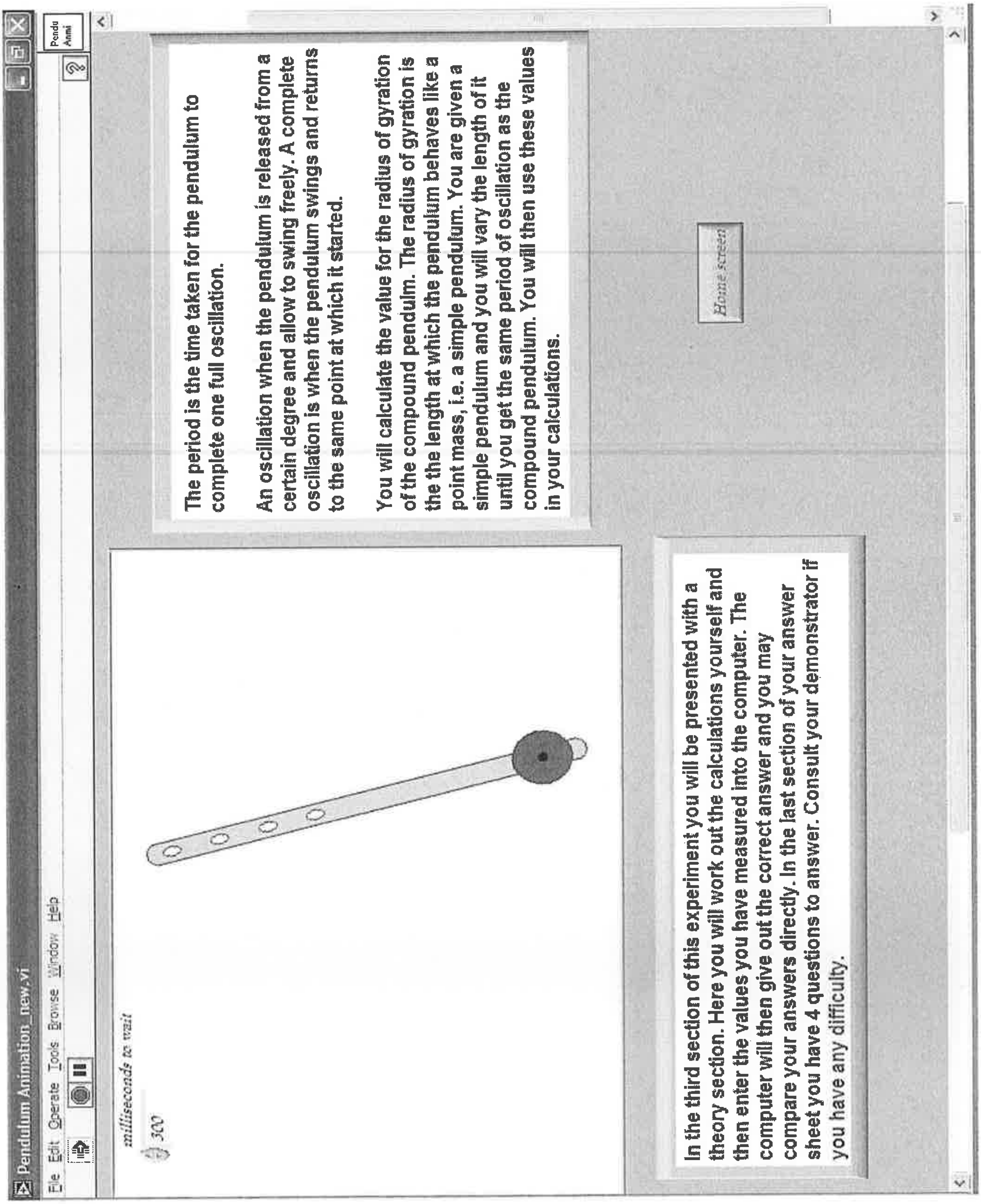


Figure A1.6 Report Requirements Screen for Flywheel Experiment

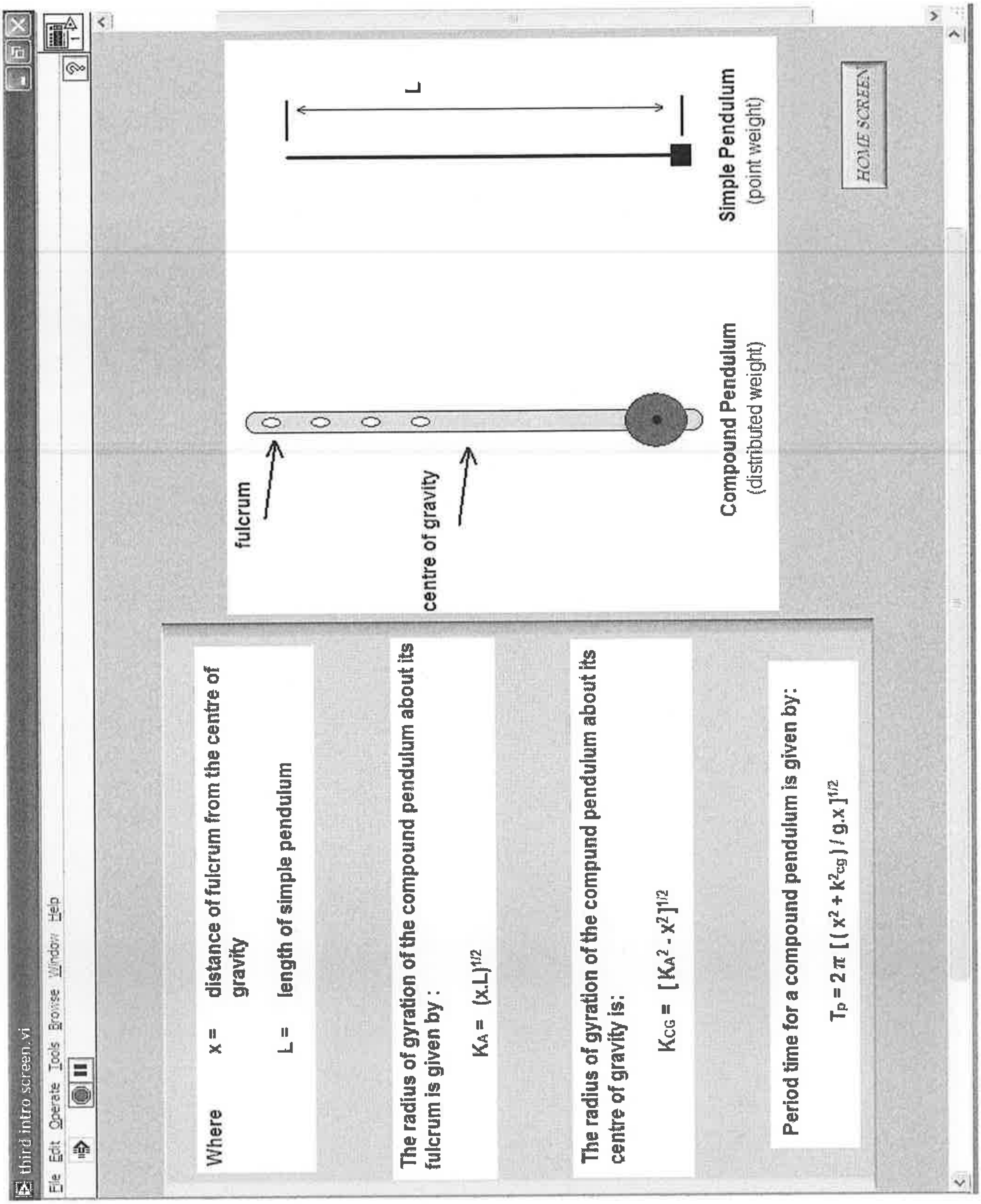
A 1.2 Compound Pendulum Experiment



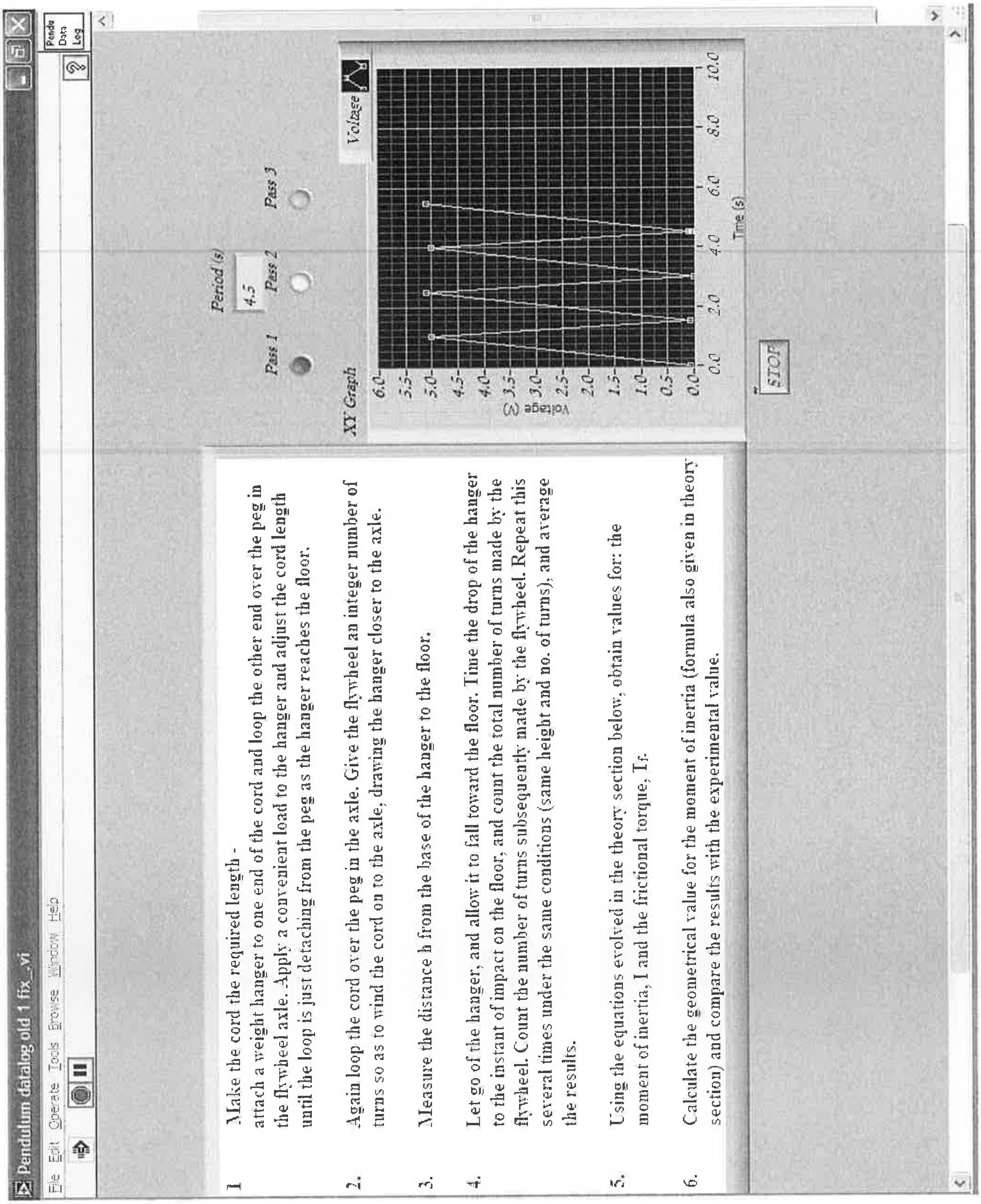
A1.7 Home Screen for Compound Pendulum Experiment



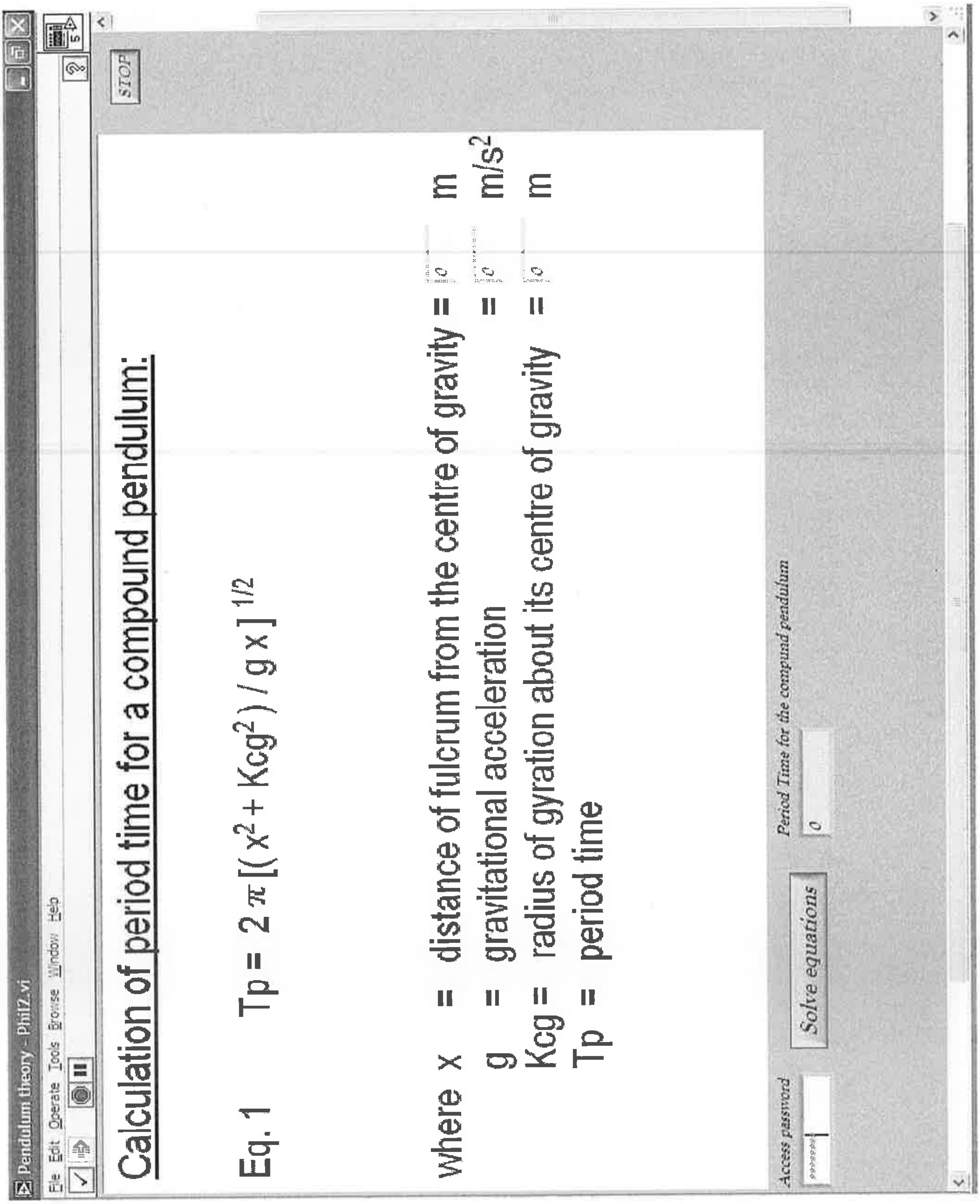
A1.8 Animation and Introduction Screen One for Compound Pendulum



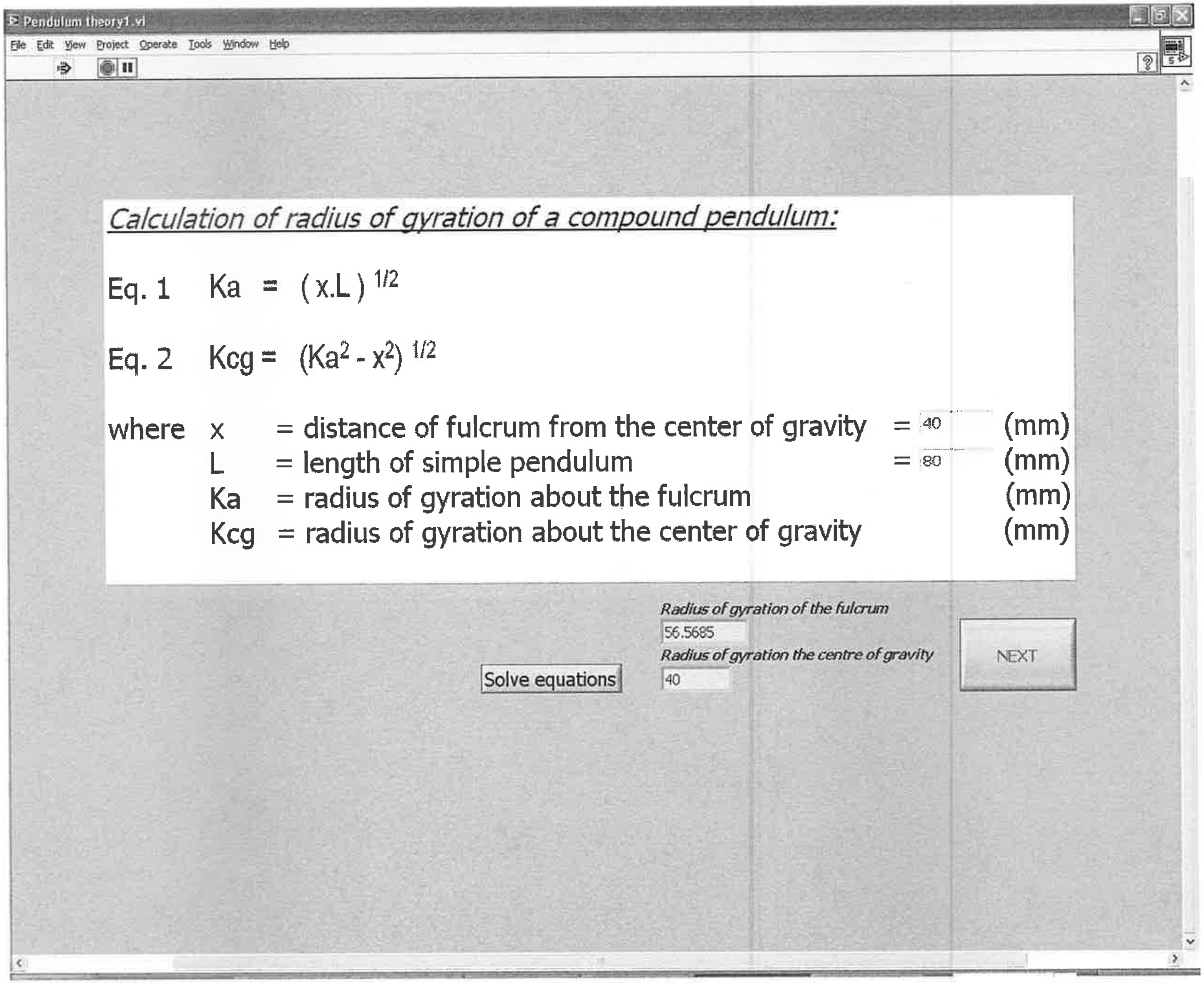
A1.9 Animation and Introduction Screen Two for Compound Pendulum



A1.10 Data Logging Screen for Compound pendulum Experiment



A1.11 Theory and Calculation Screen One for Compound Pendulum



A1.12 Theory and Calculation Screen Two for Compound Pendulum

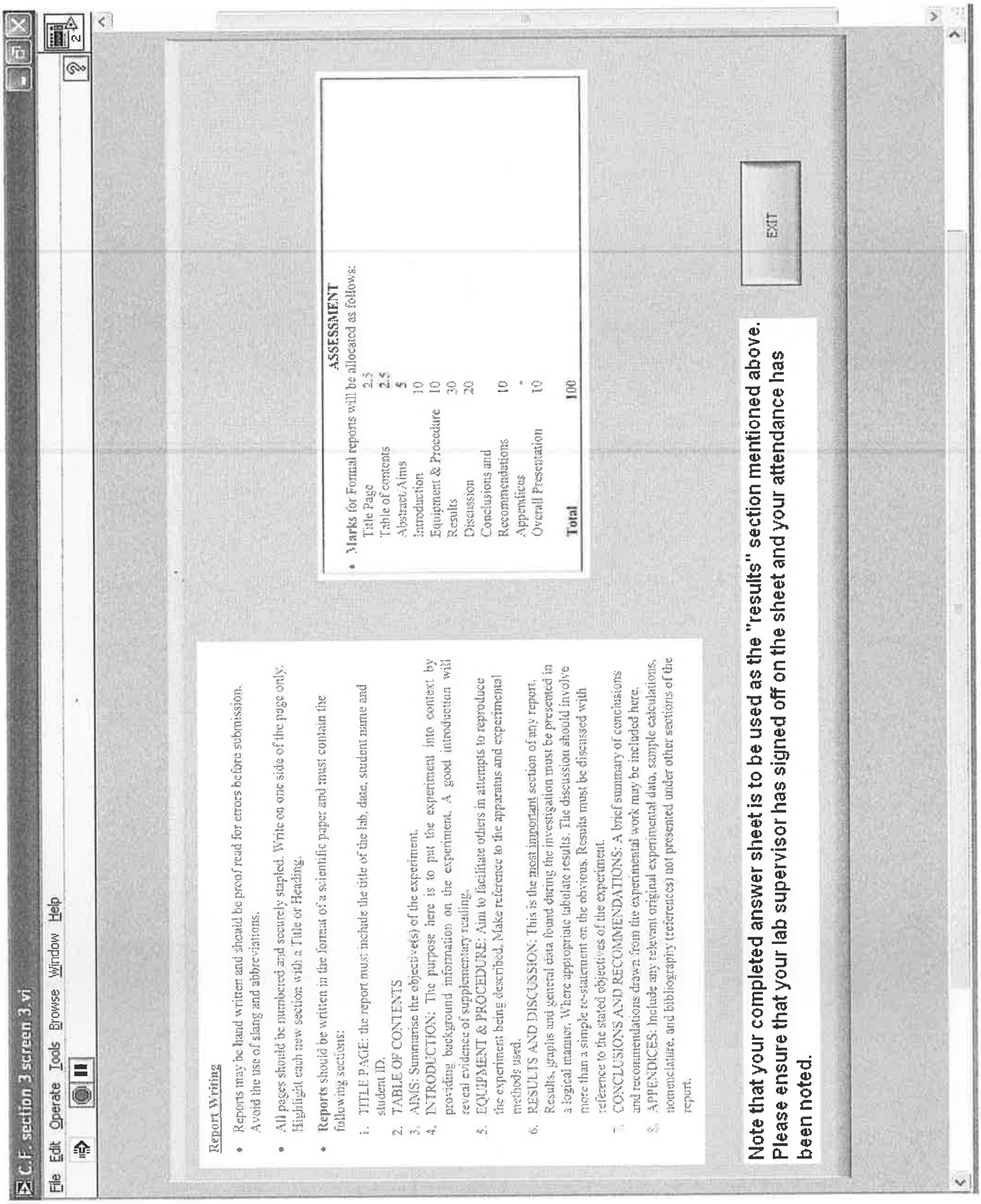


Figure A1.13 Report Requirements Screen for Compound Pendulum Experiment

A 1.3 Centrifugal Force Experiment

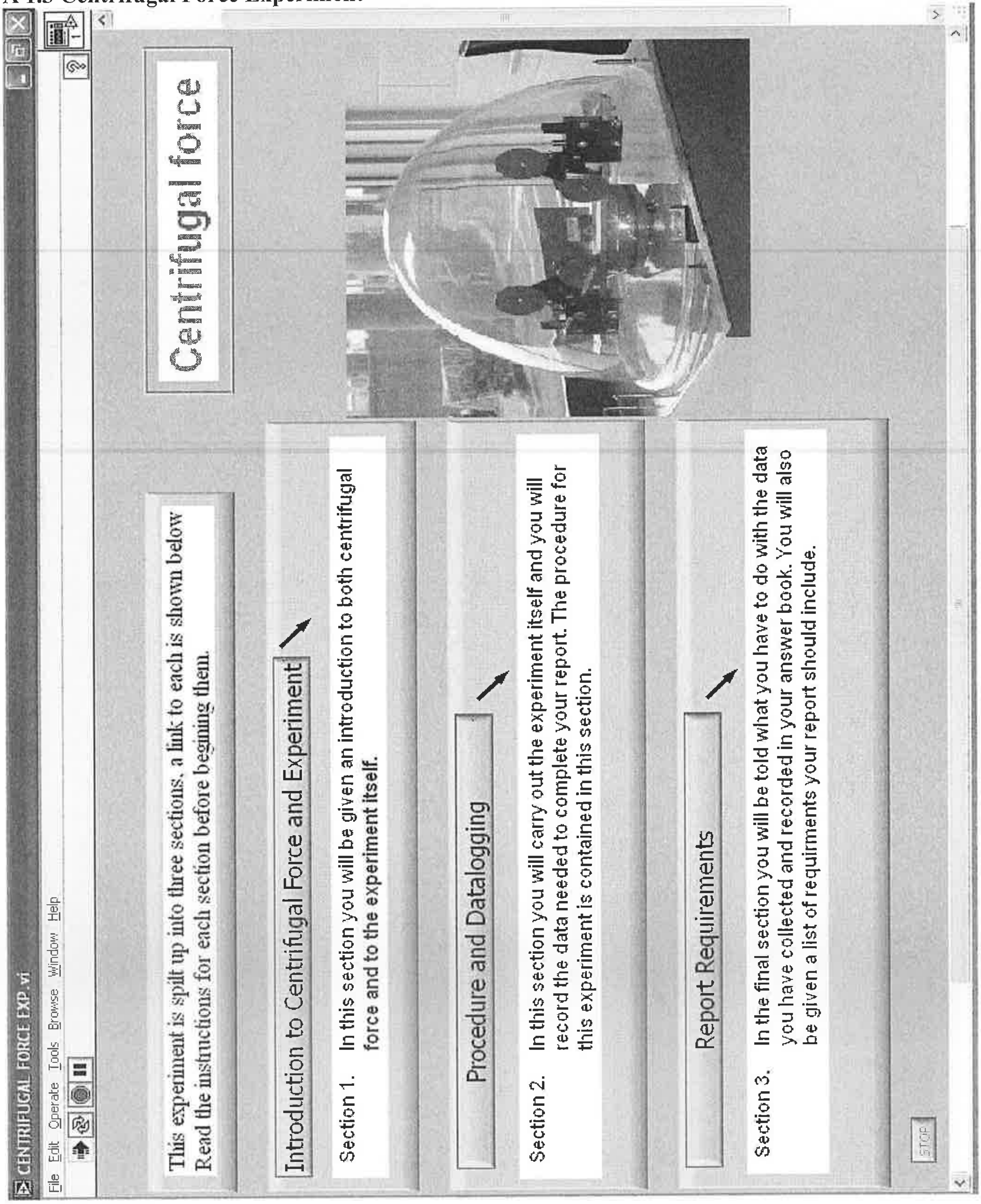
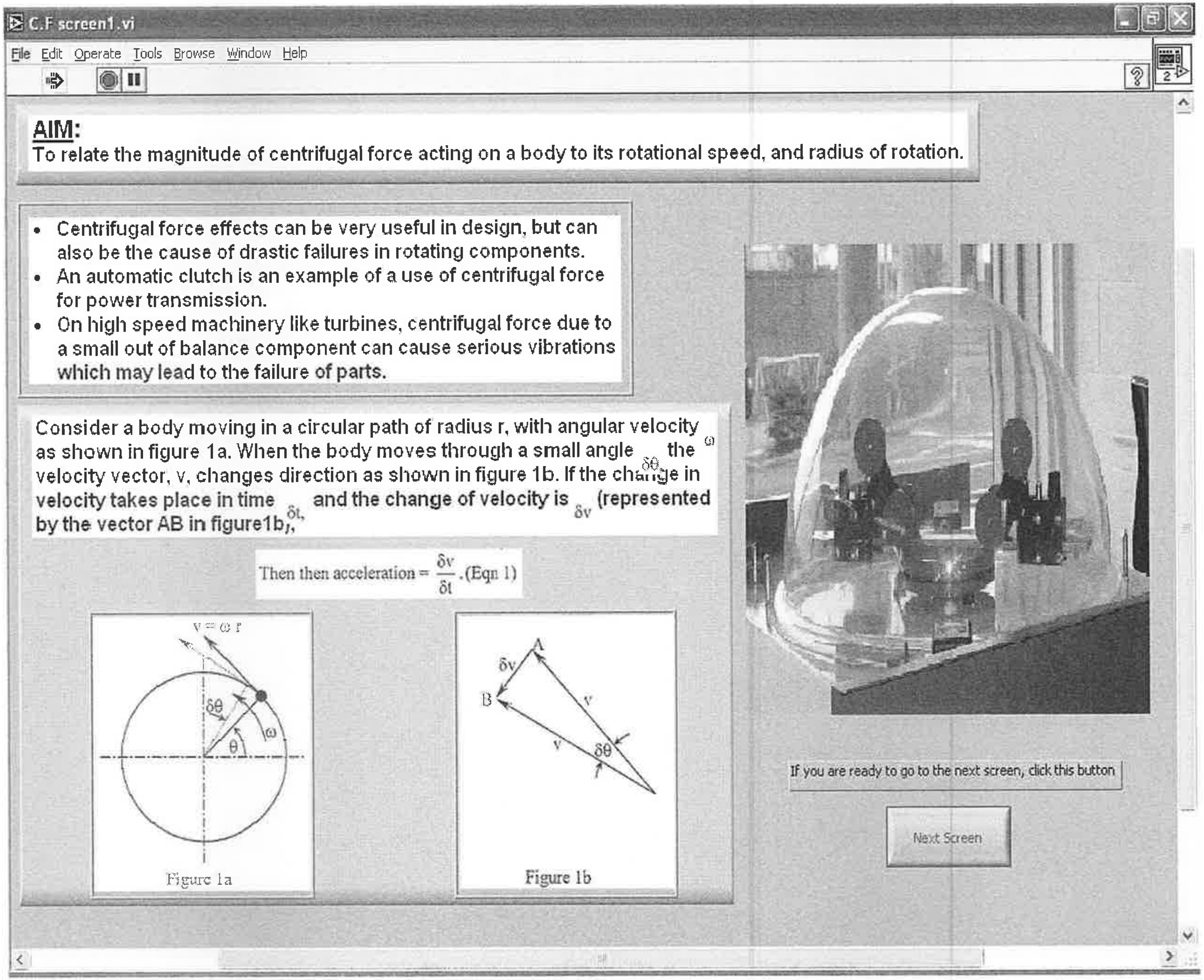
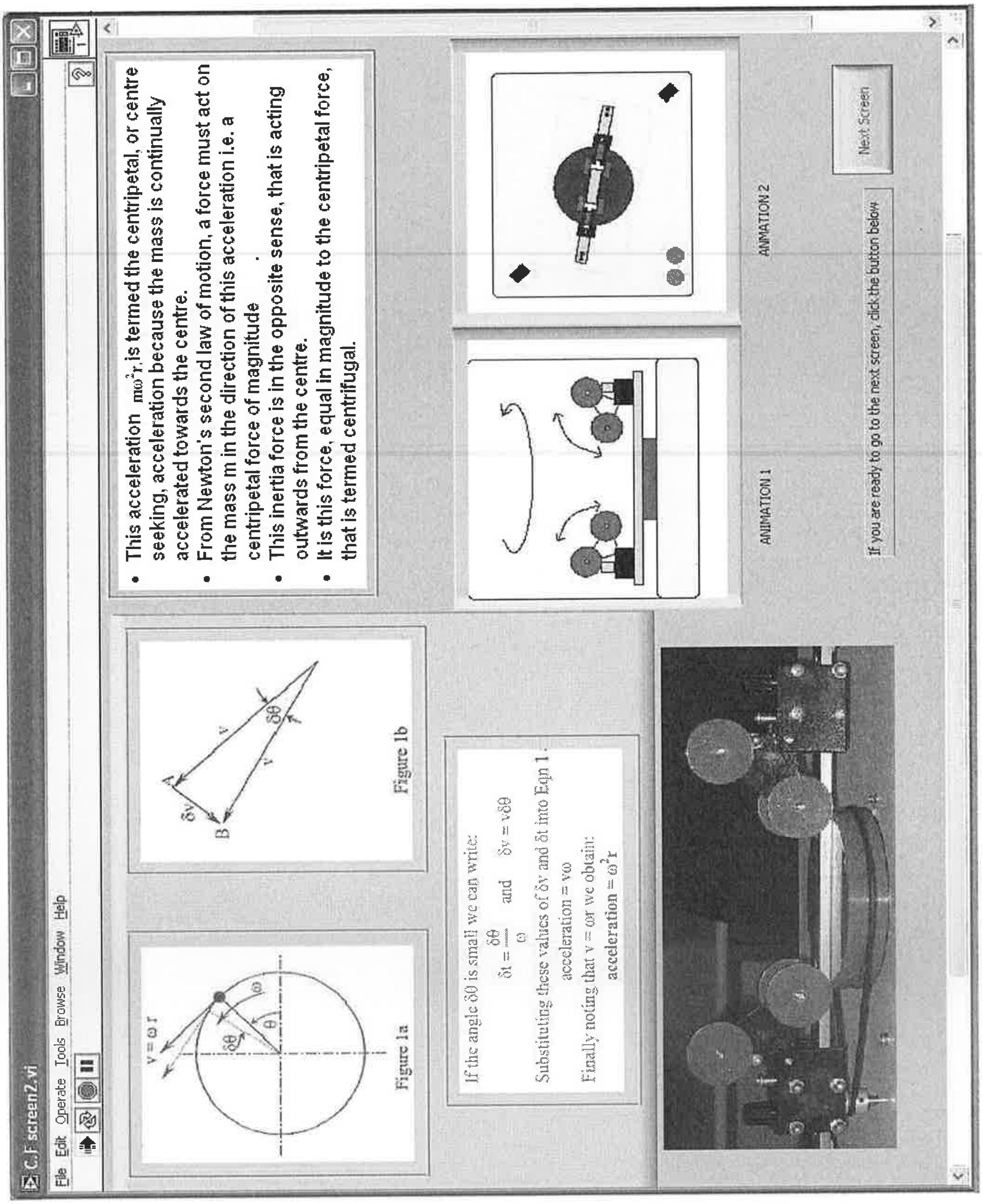


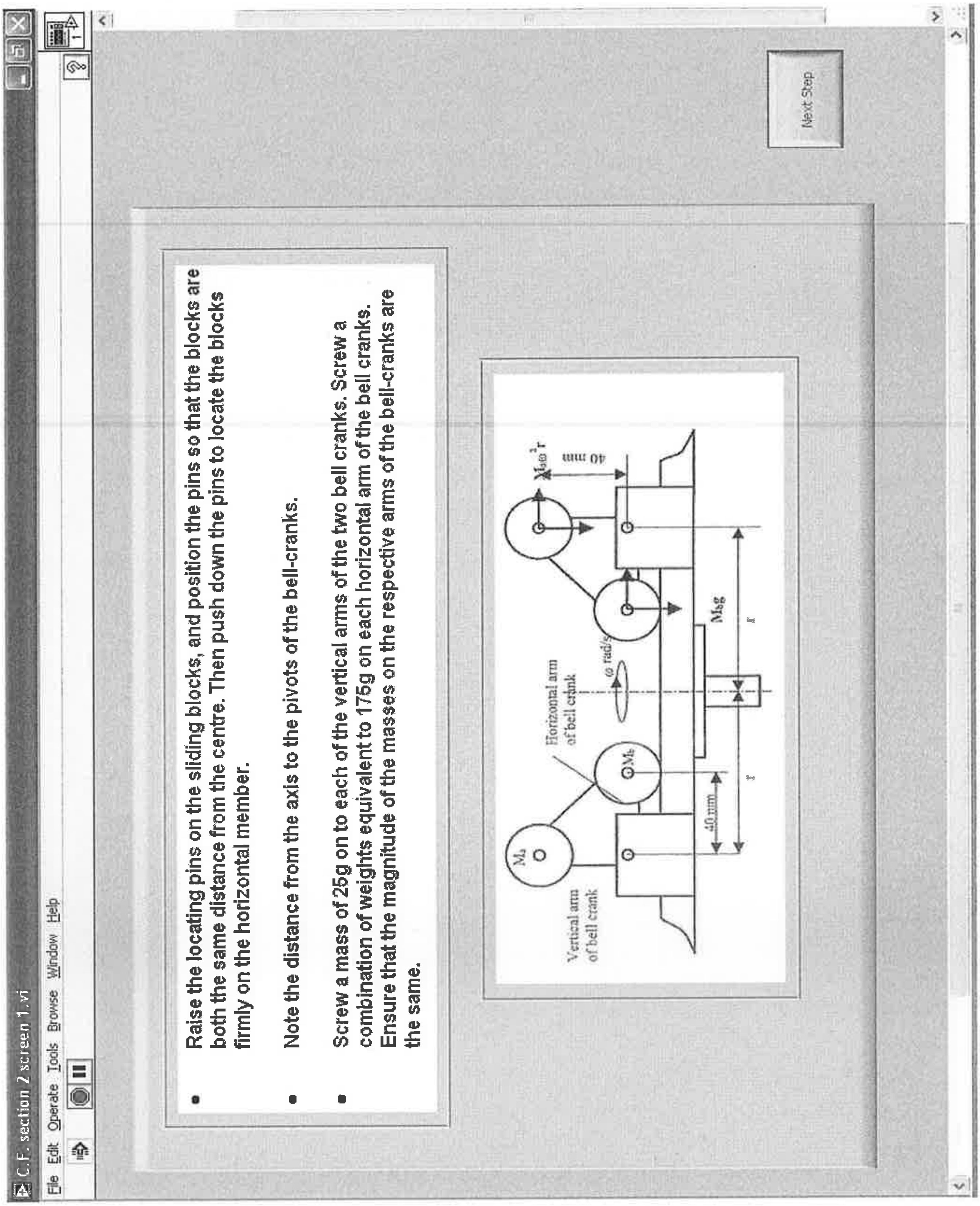
Figure A1.14 Home Screen for Centrifugal Force Experiment



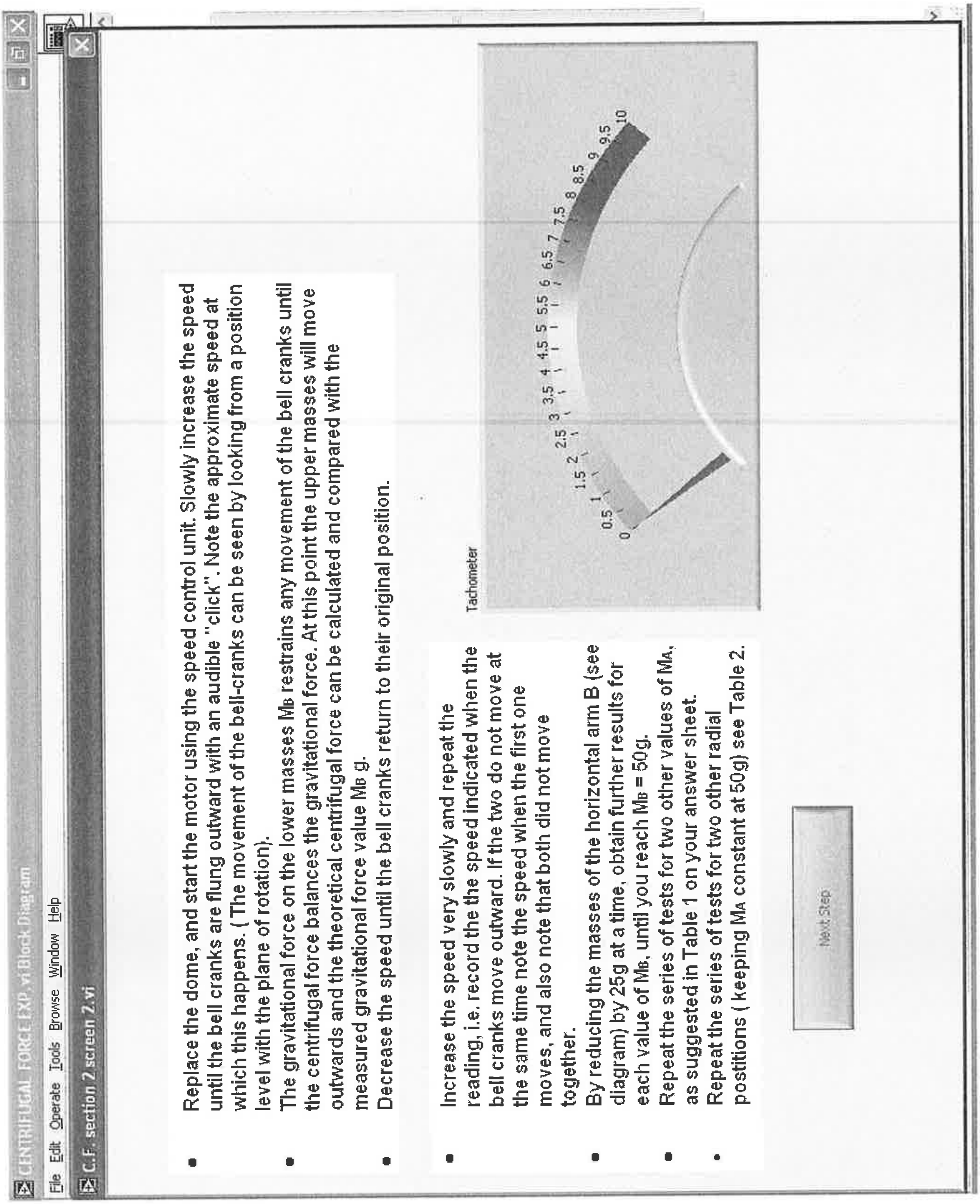
A1.15 Animation Screen One for Centrifugal Force Experiment



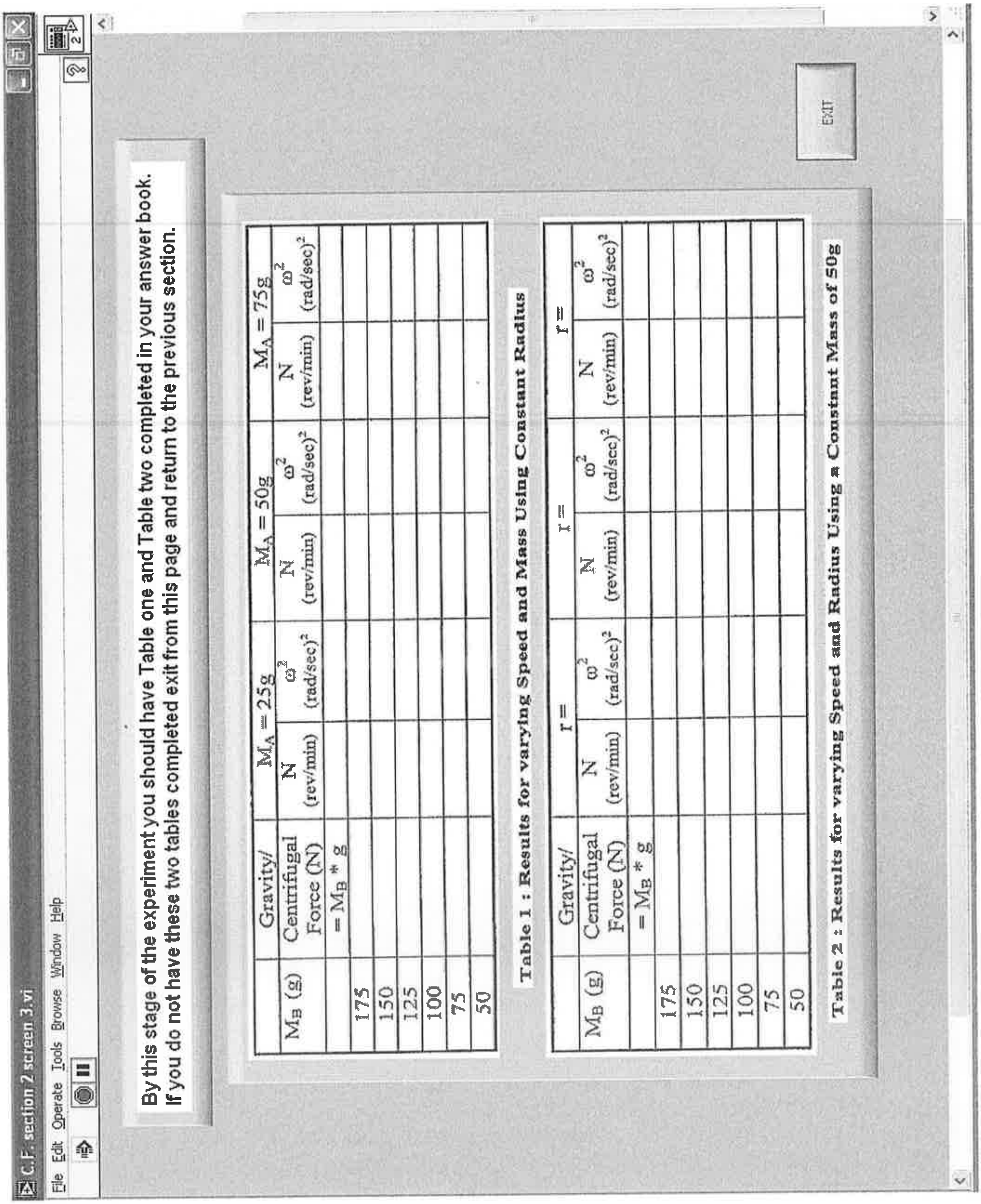
A1.16 Animation Screen Two for Centrifugal Force Experiment



A1.17 Procedure and Data Logging Screen One for Centrifugal Force Experiment



A1.18 Procedure and Data Logging Screen Two for Centrifugal Force Experiment



C.F. section 2 screen 3.vi

File Edit Operate Tools Browse Window Help

By this stage of the experiment you should have Table one and Table two completed in your answer book.
If you do not have these two tables completed exit from this page and return to the previous section.

M_B (g)	Gravity/ Centrifugal Force (N)	M_A = 25g		M_A = 50g		M_A = 75g	
	$= M_B * g$	N (rev/min)	ω^2 (rad/sec)^2	N (rev/min)	ω^2 (rad/sec)^2	N (rev/min)	ω^2 (rad/sec)^2
175							
150							
125							
100							
75							
50							

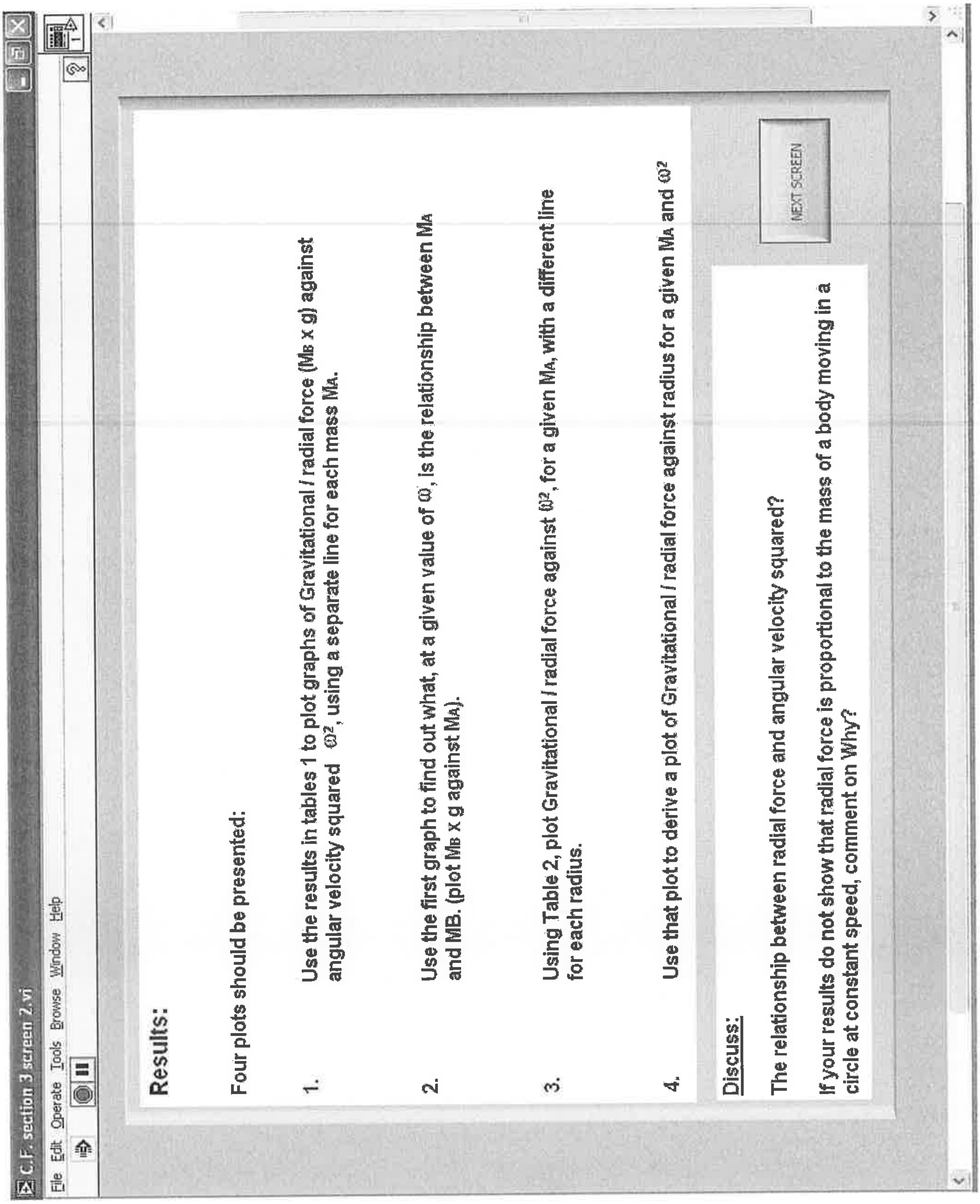
Table 1 : Results for varying Speed and Mass Using Constant Radius

M_B (g)	Gravity/ Centrifugal Force (N)	r =		r =		r =	
	$= M_B * g$	N (rev/min)	ω^2 (rad/sec)^2	N (rev/min)	ω^2 (rad/sec)^2	N (rev/min)	ω^2 (rad/sec)^2
175							
150							
125							
100							
75							
50							

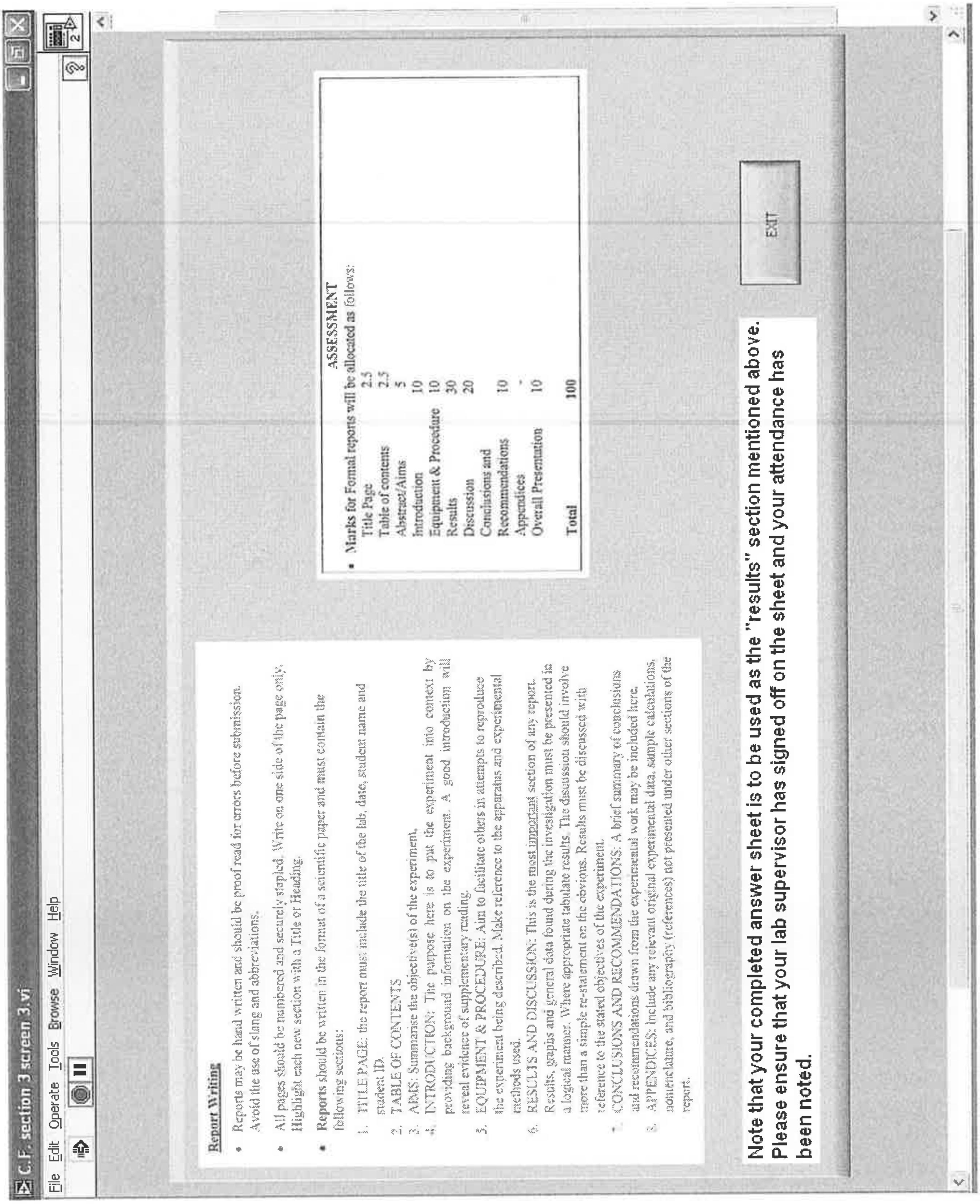
Table 2 : Results for varying Speed and Radius Using a Constant Mass of 50g

EXIT

A1.19 Procedure and Data Logging Screen Three for Centrifugal Force Experiment

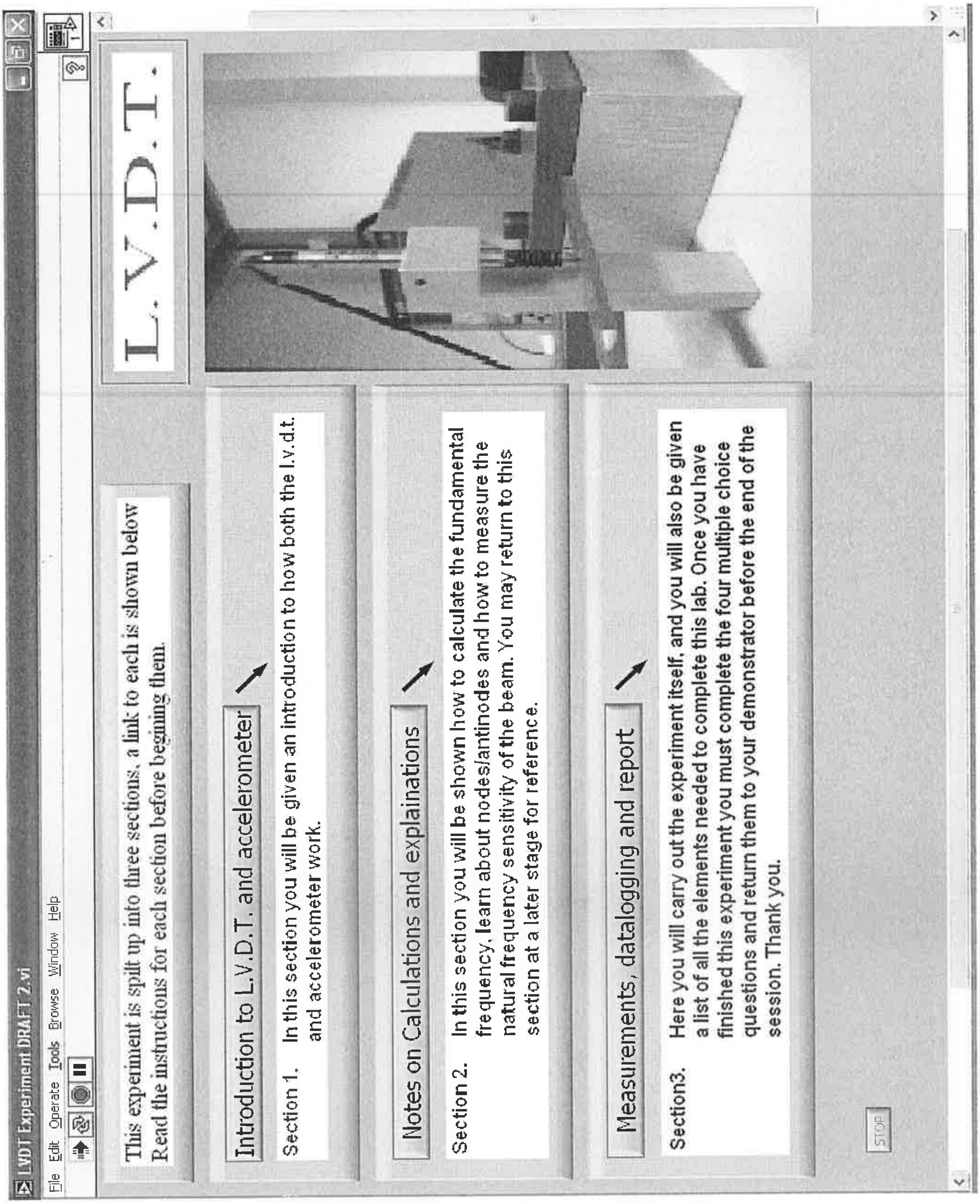


A1.20 Calculation and Report Requirements Screen One for Centrifugal Force Experiment

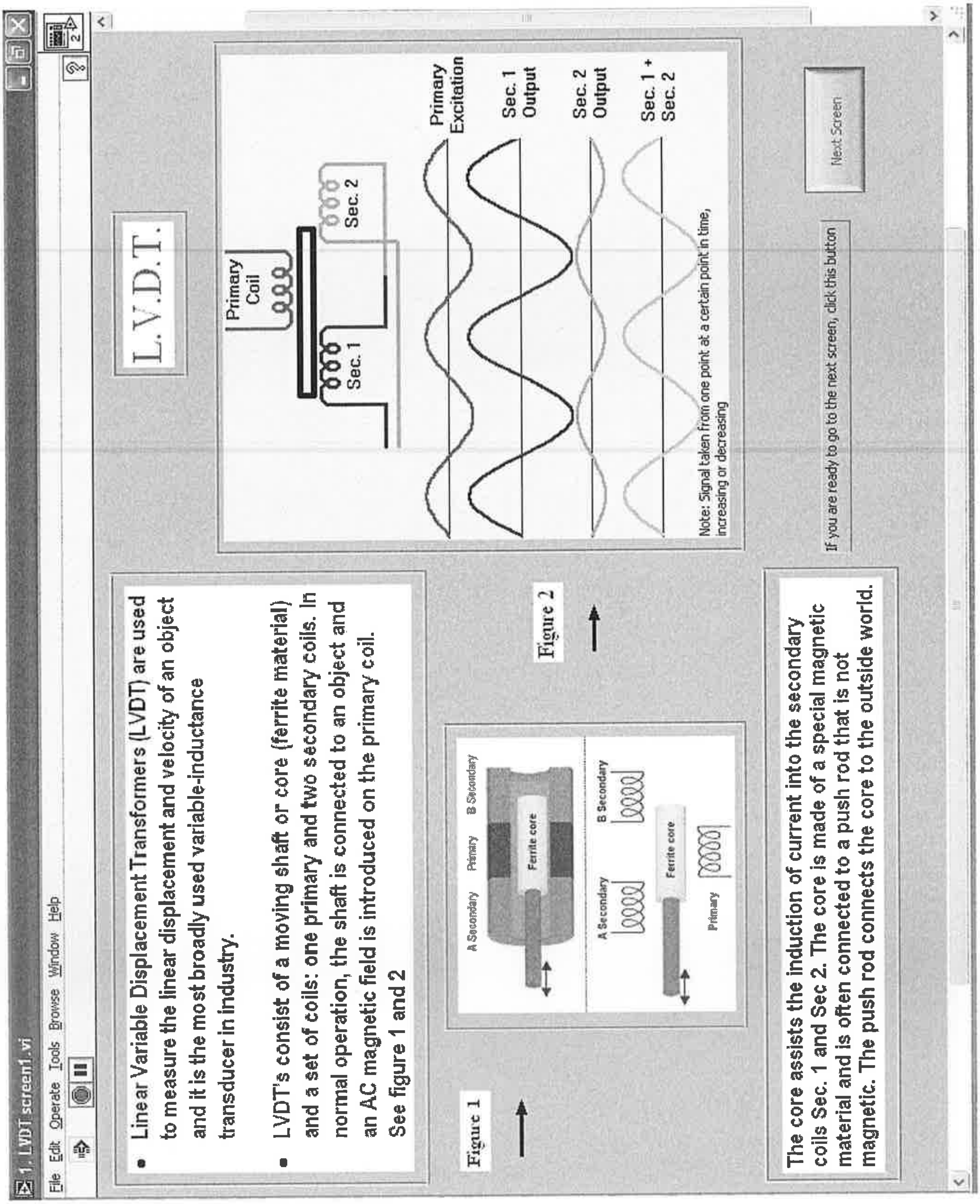


A1.21 Calculation and Report Requirements Screen Two for Centrifugal Force Experiment

A 1.4 L.V.D.T. Experiment



A1.22 Figure Home Screen for L.V.D.T. Experiment



A1.23 Introduction and Animation Screen One for LVDT Experiment

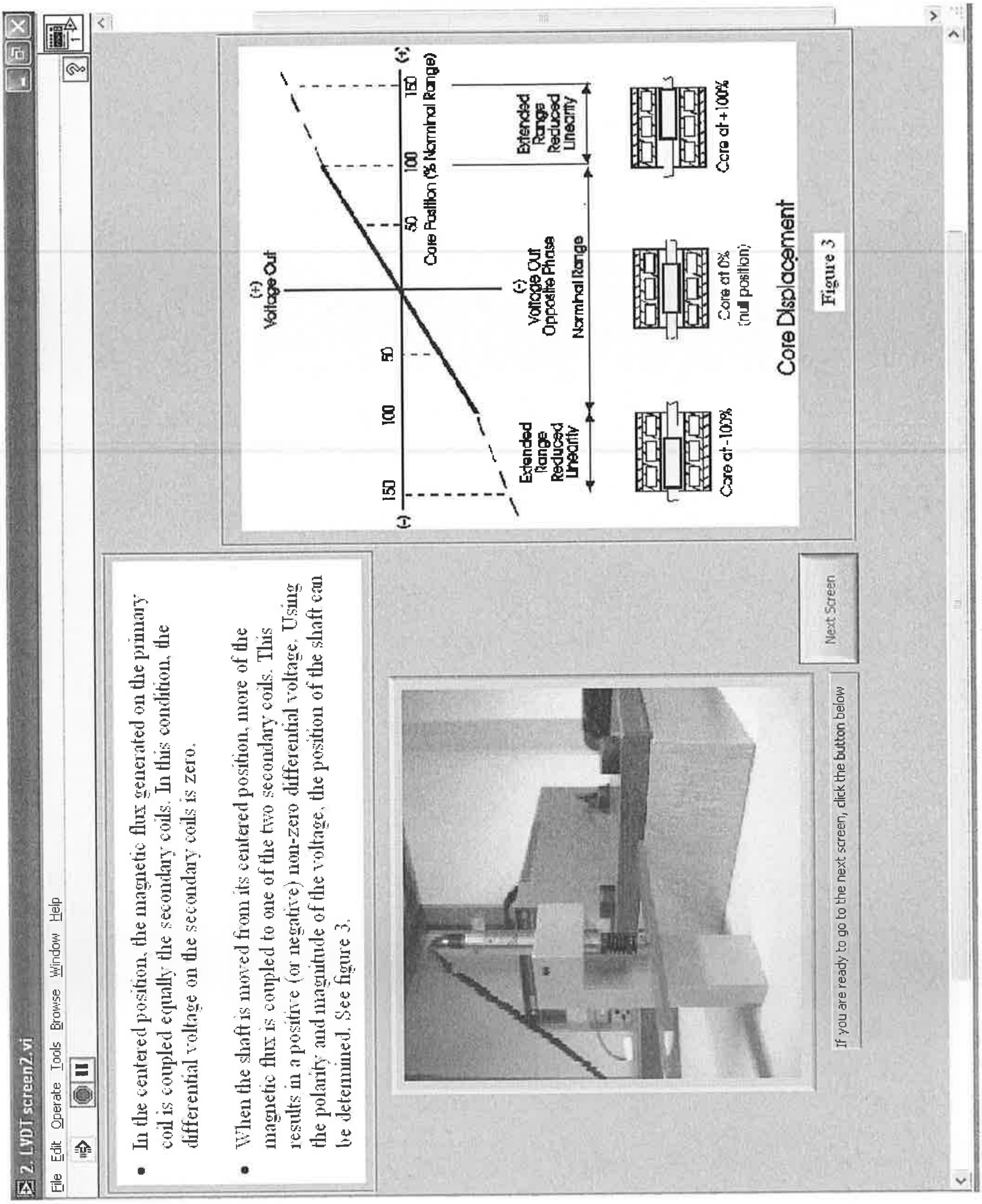


Figure A1.24 Introduction and Animation Screen Two for LVDT Experiment

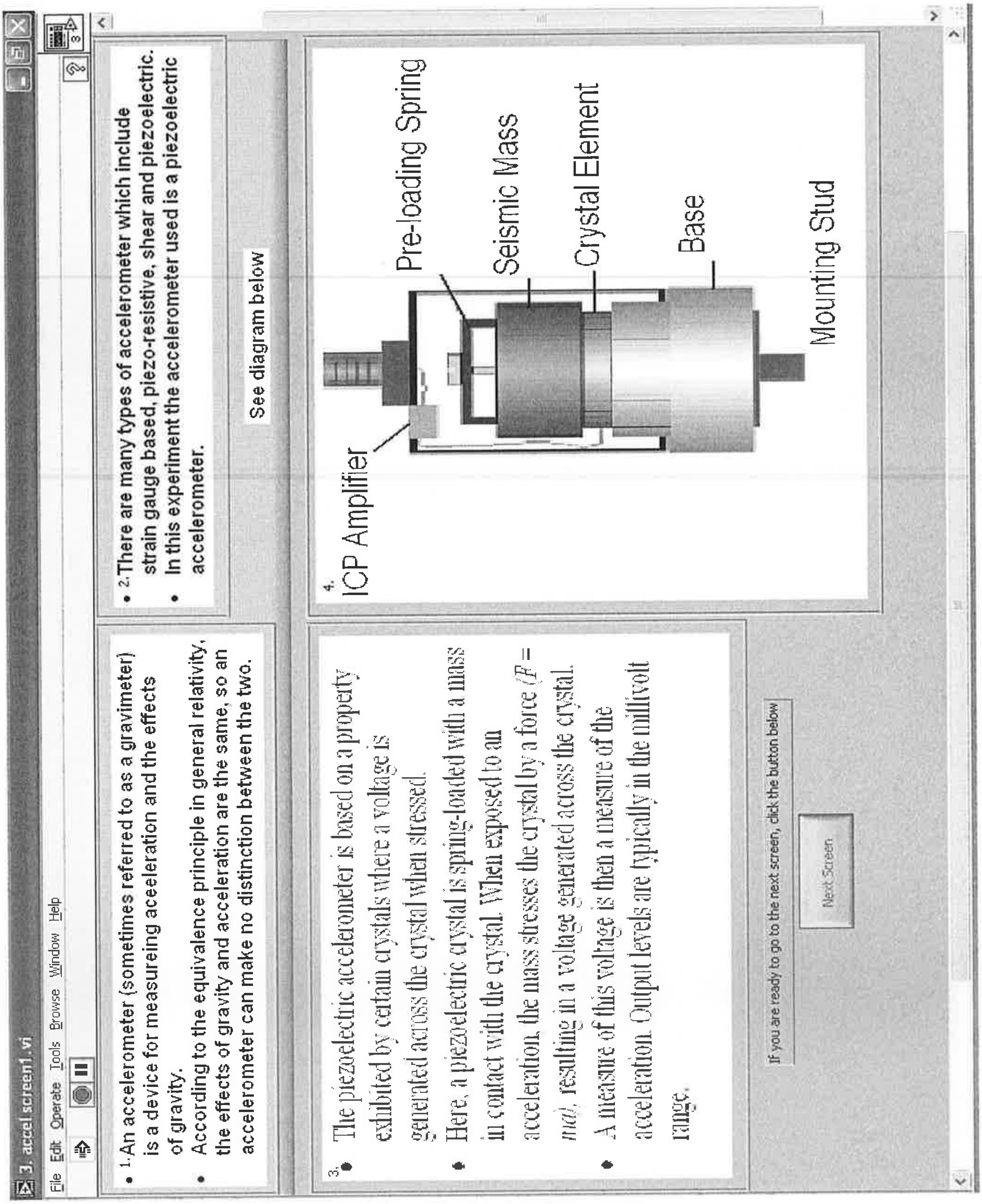
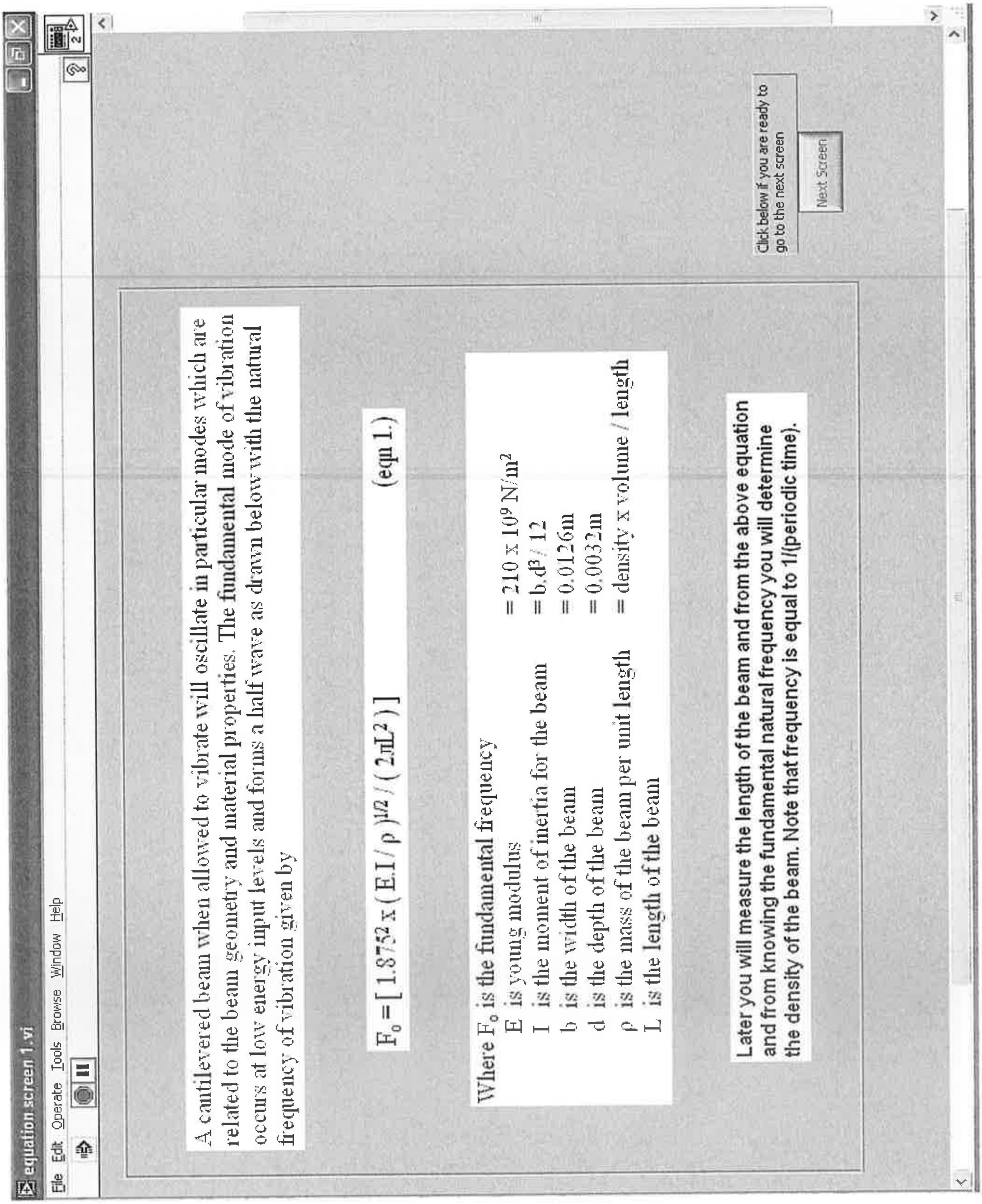
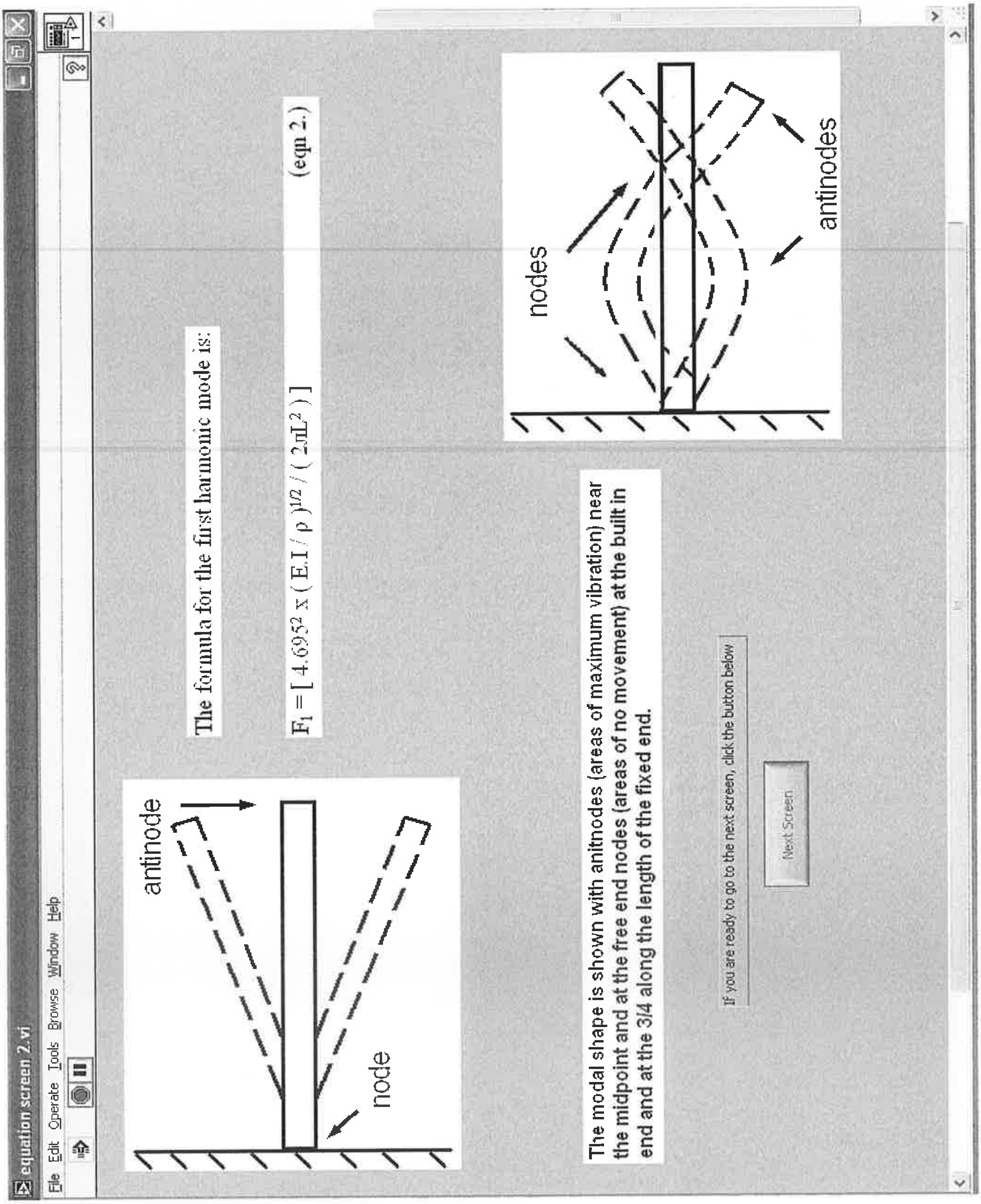


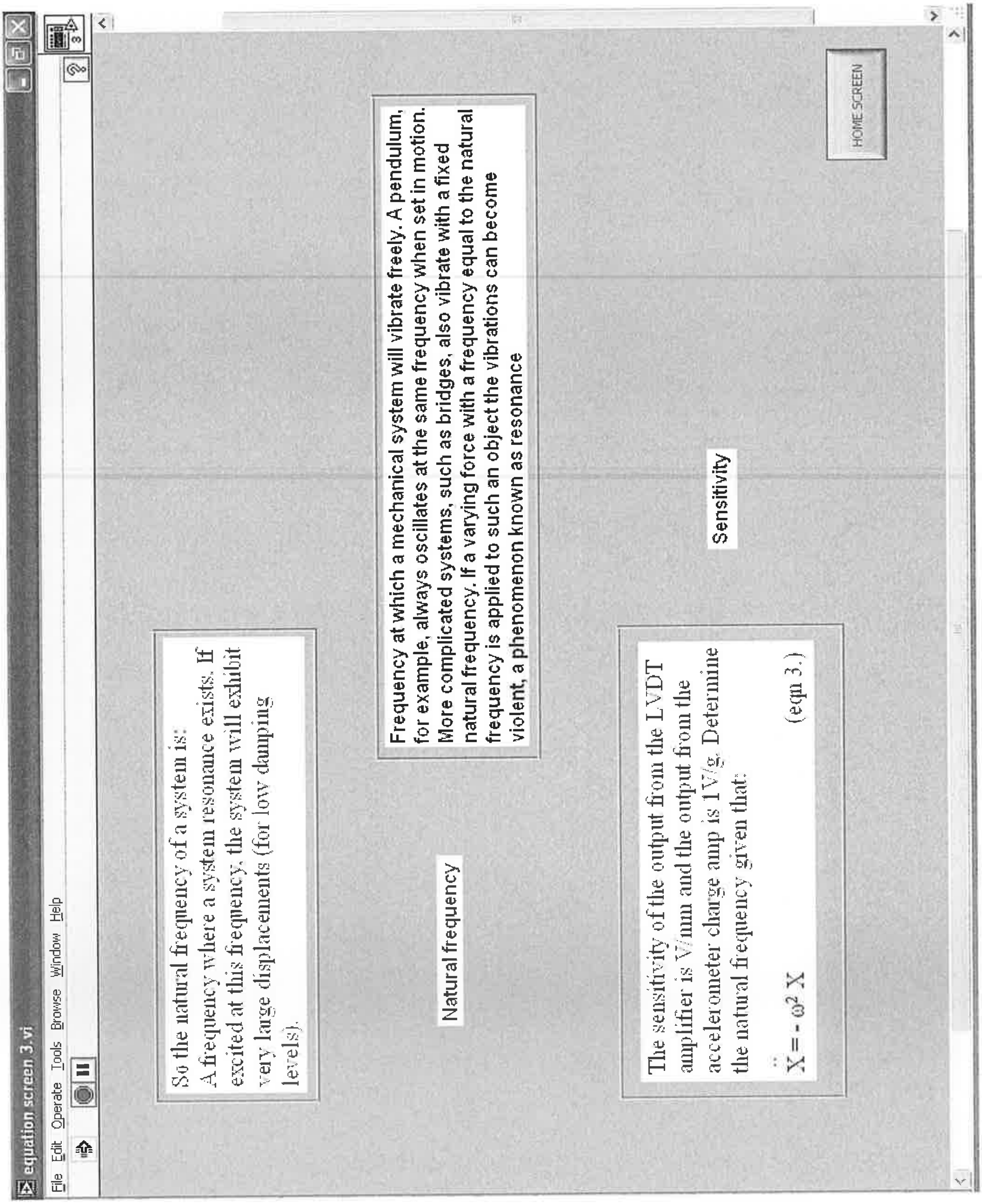
Figure A1.25 Introduction and Animation Screen Three for LVDT Experiment



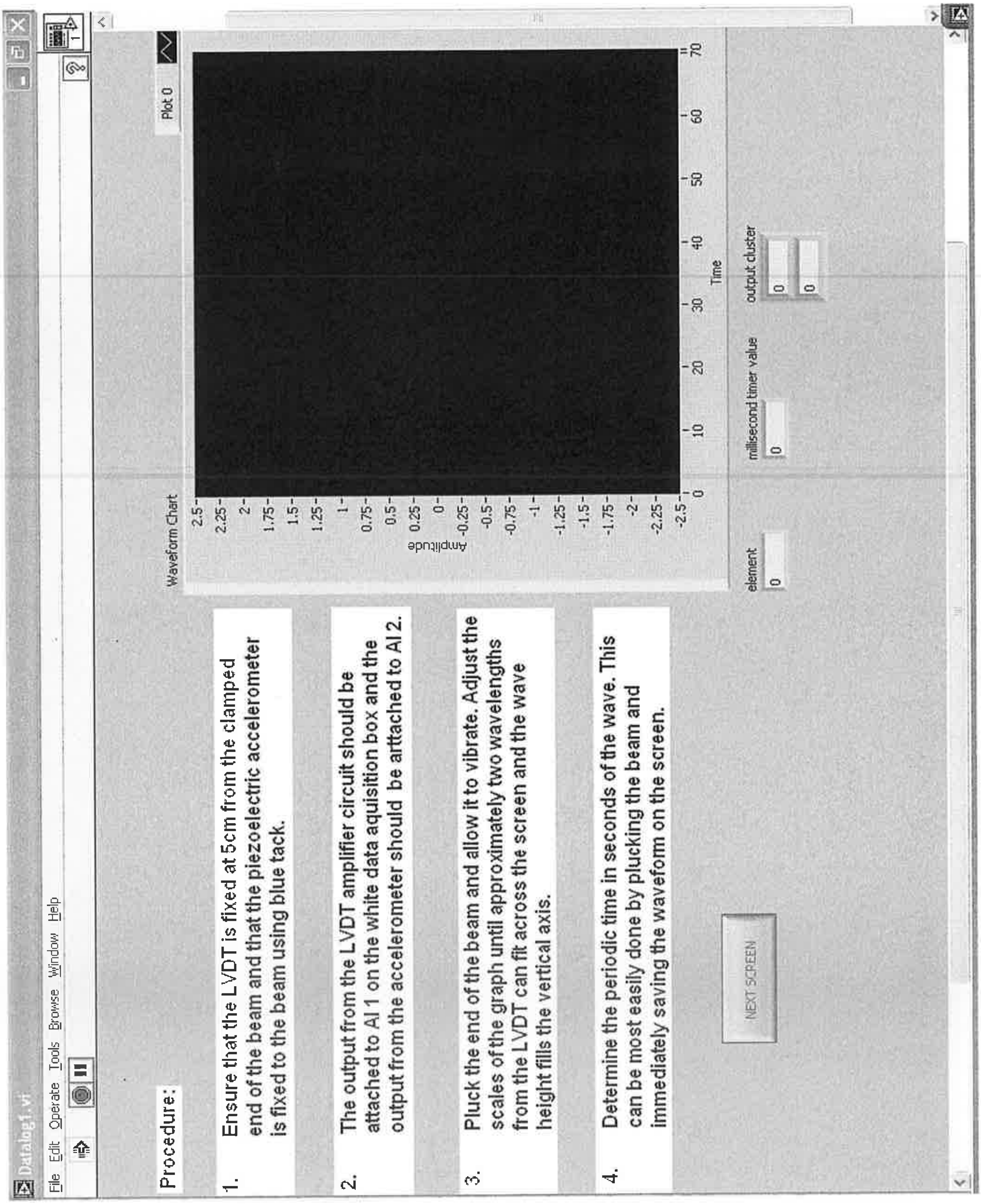
A1.26 Procedure and Datalogging Screen One for LVDT Experiment



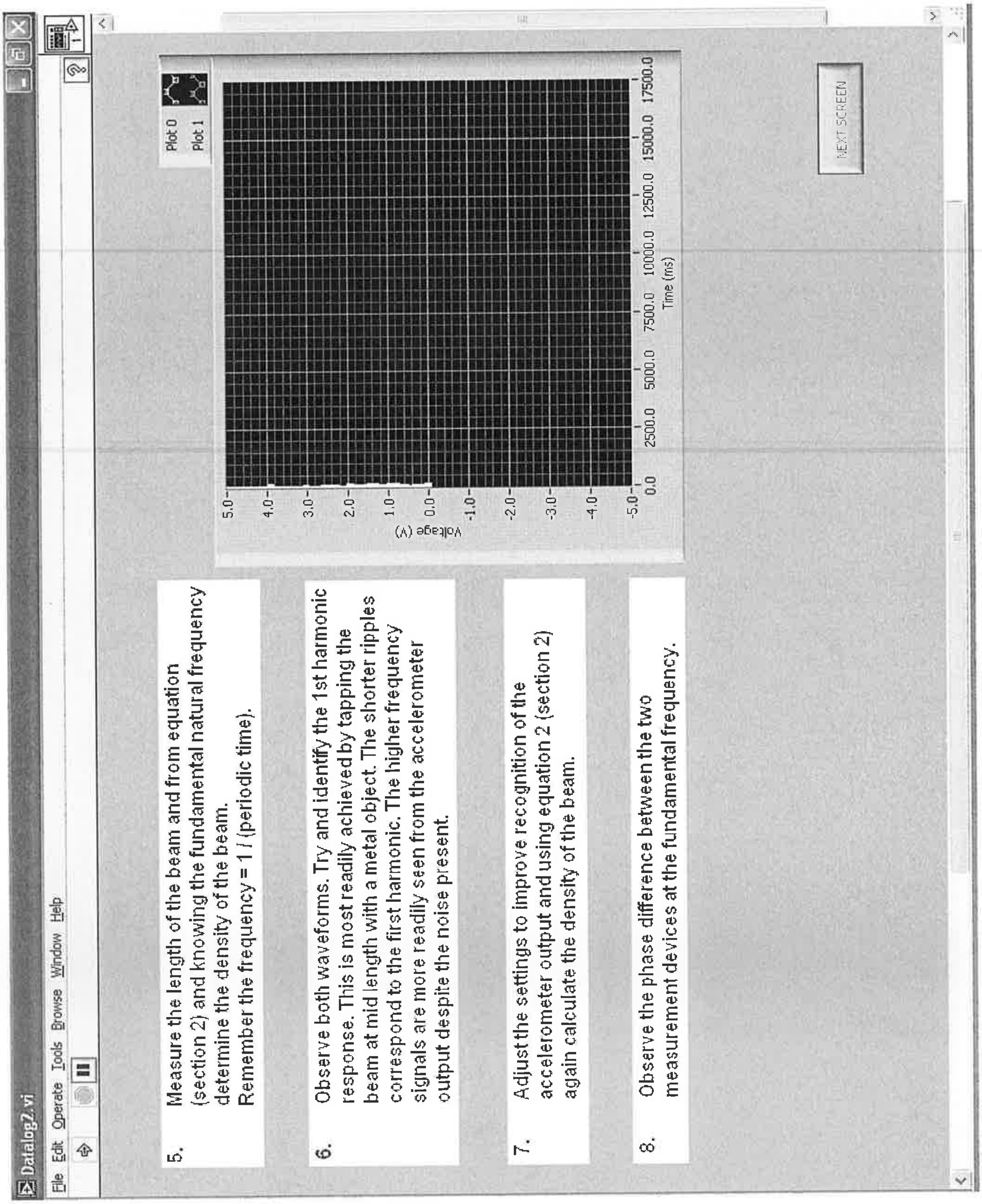
A1.27 Procedure and Datalogging Screen Two for LVDT Experiment



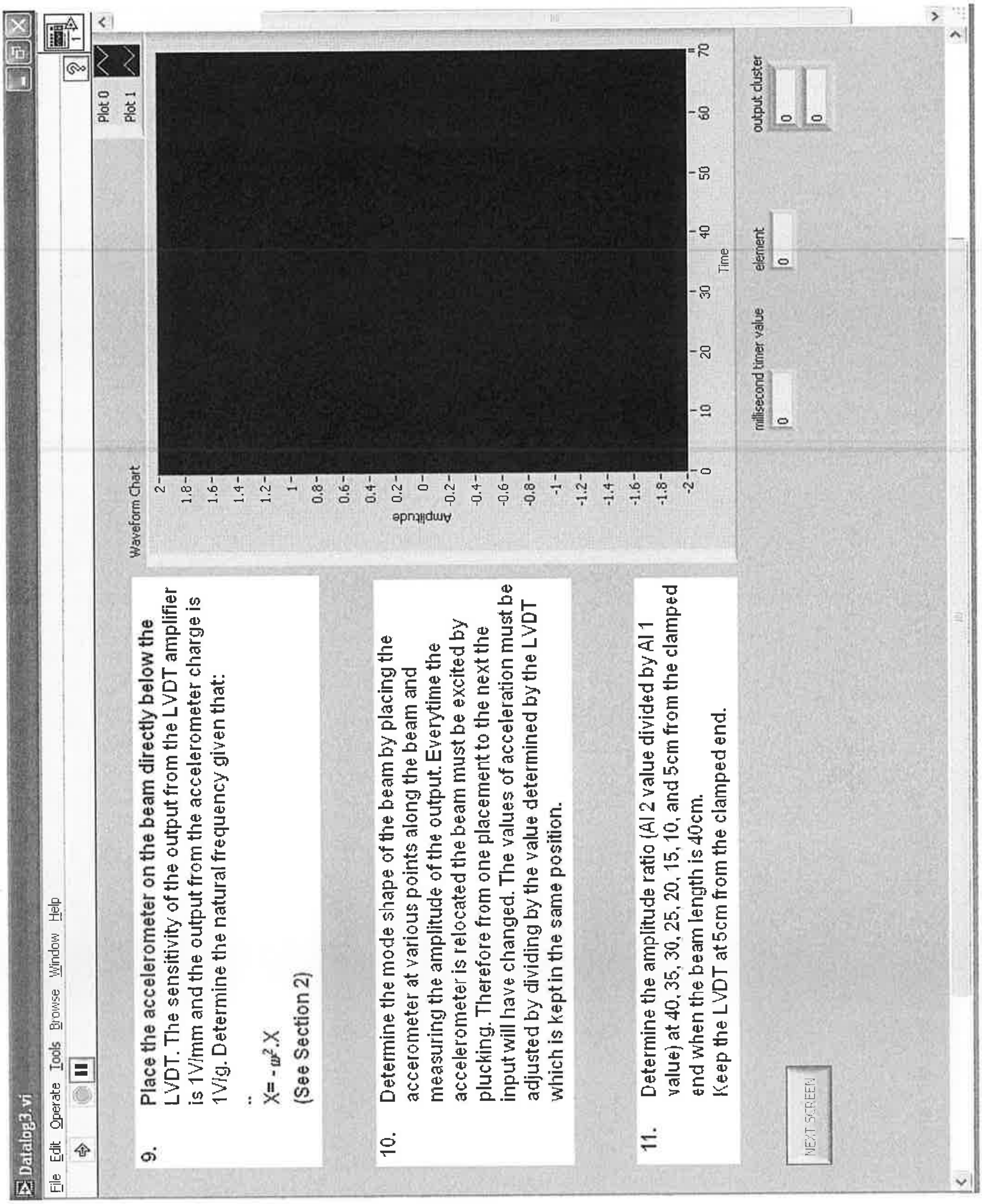
A1.28 Procedure and Datalogging Screen Three for LVDT Experiment



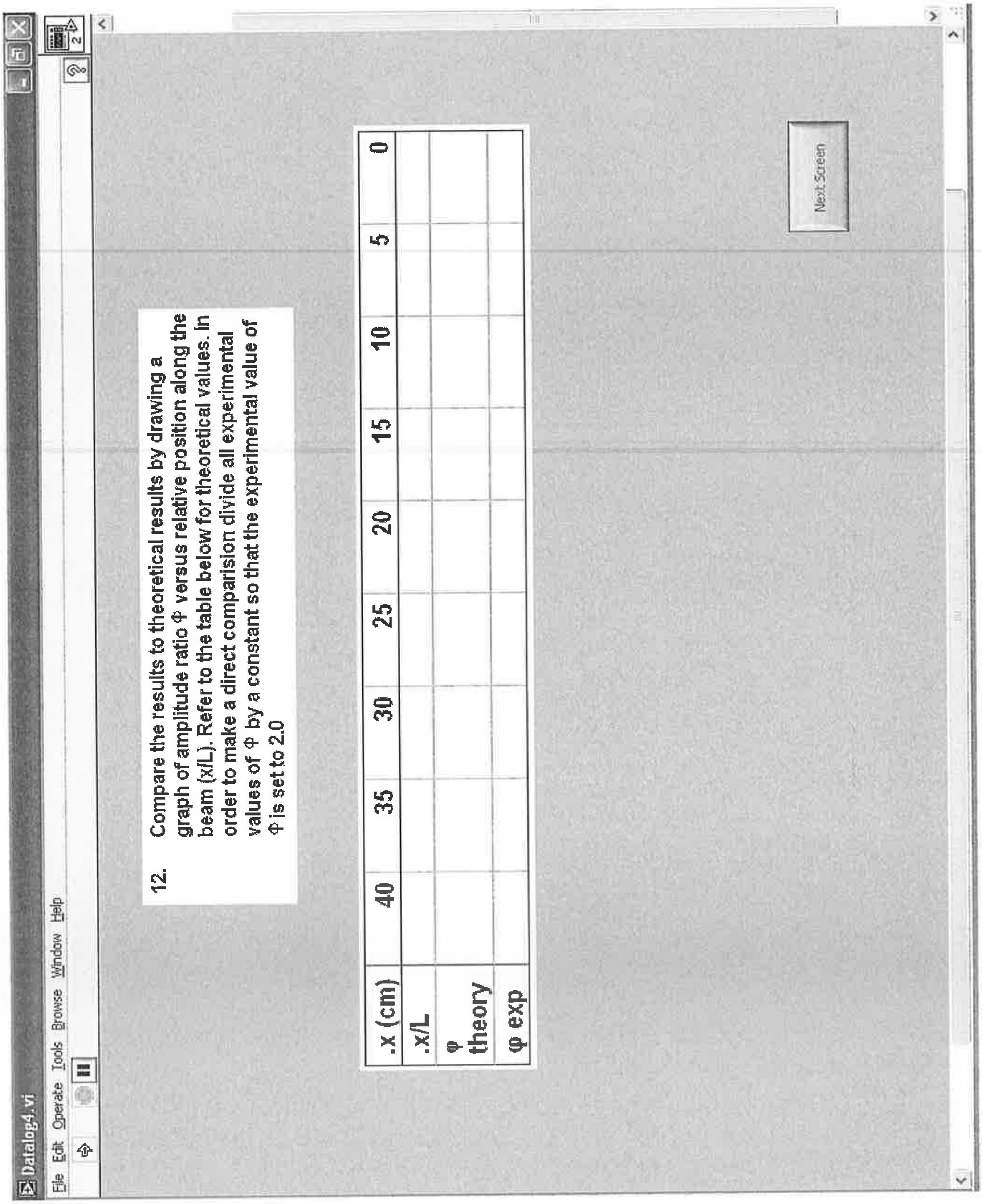
A1.29 Procedure and Datalogging Screen Four for LVDT Experiment



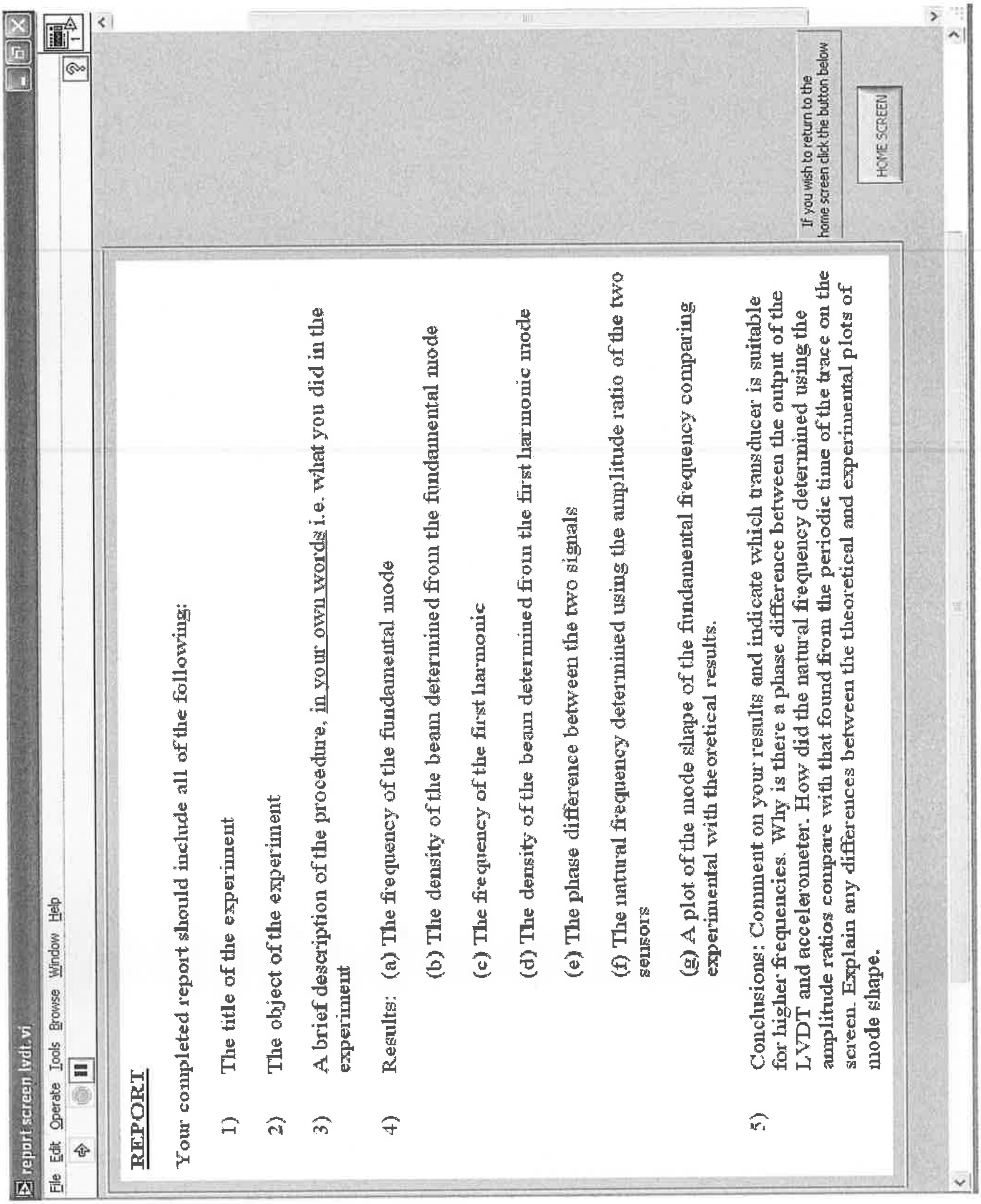
A1.30 Procedure and Datalogging Screen Five for LVDT Experiment



A1.31 Procedure and Datalogging Screen Six for LVDT Experiment

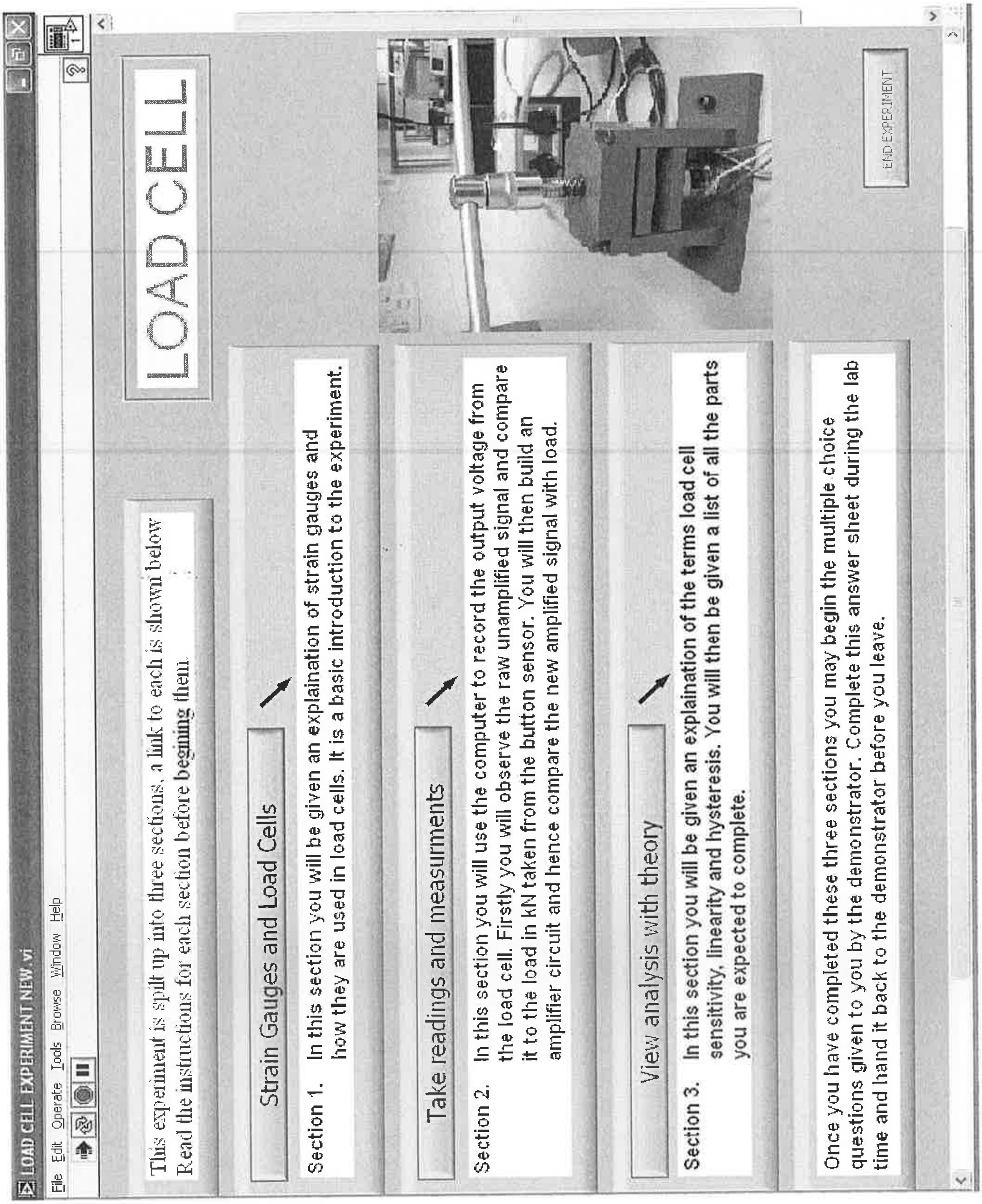


A1.32 Procedure and Datalogging Screen Seven for LVDT Experiment

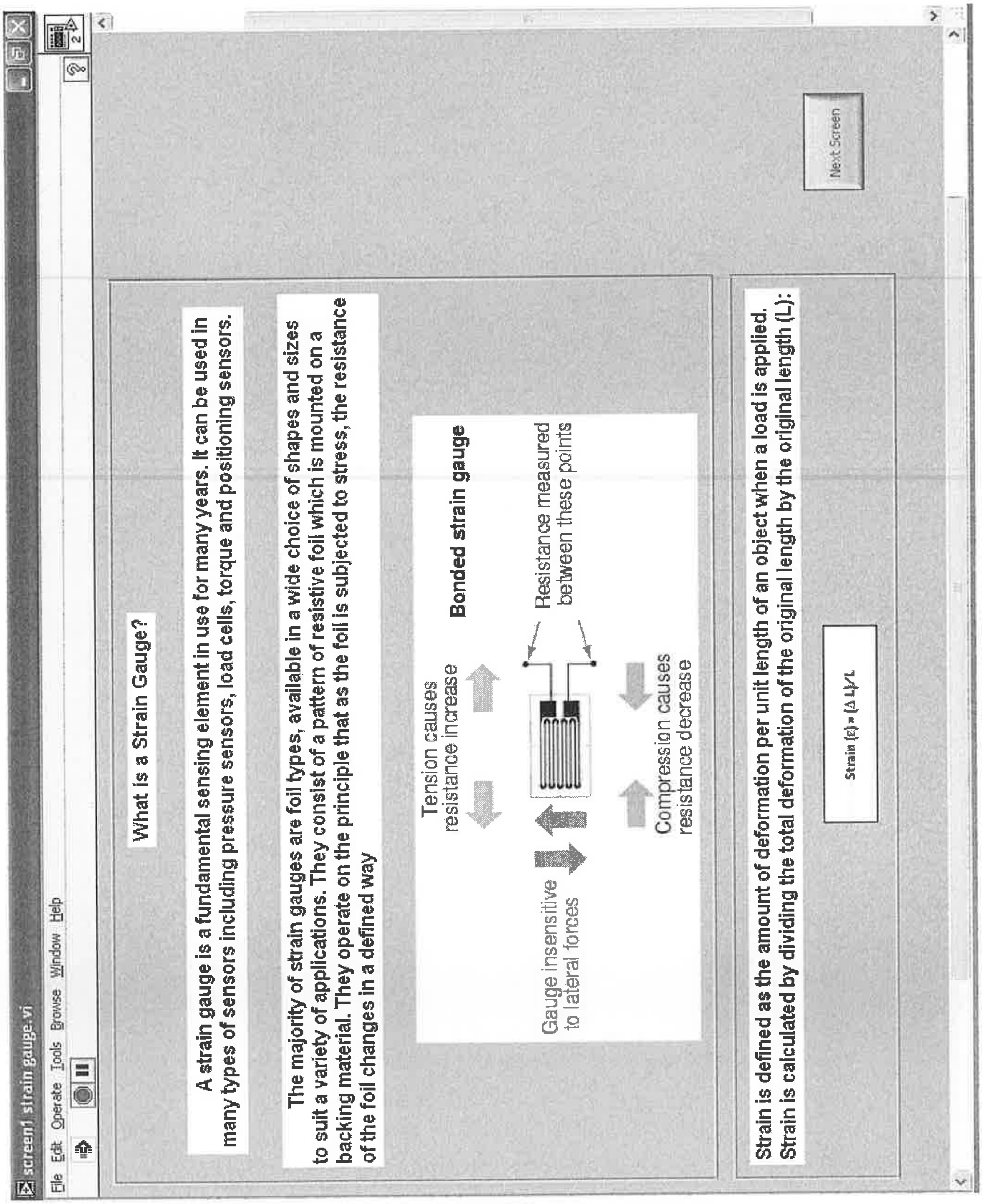


A1.33 Report Requirements Screen for LVDT Experiment

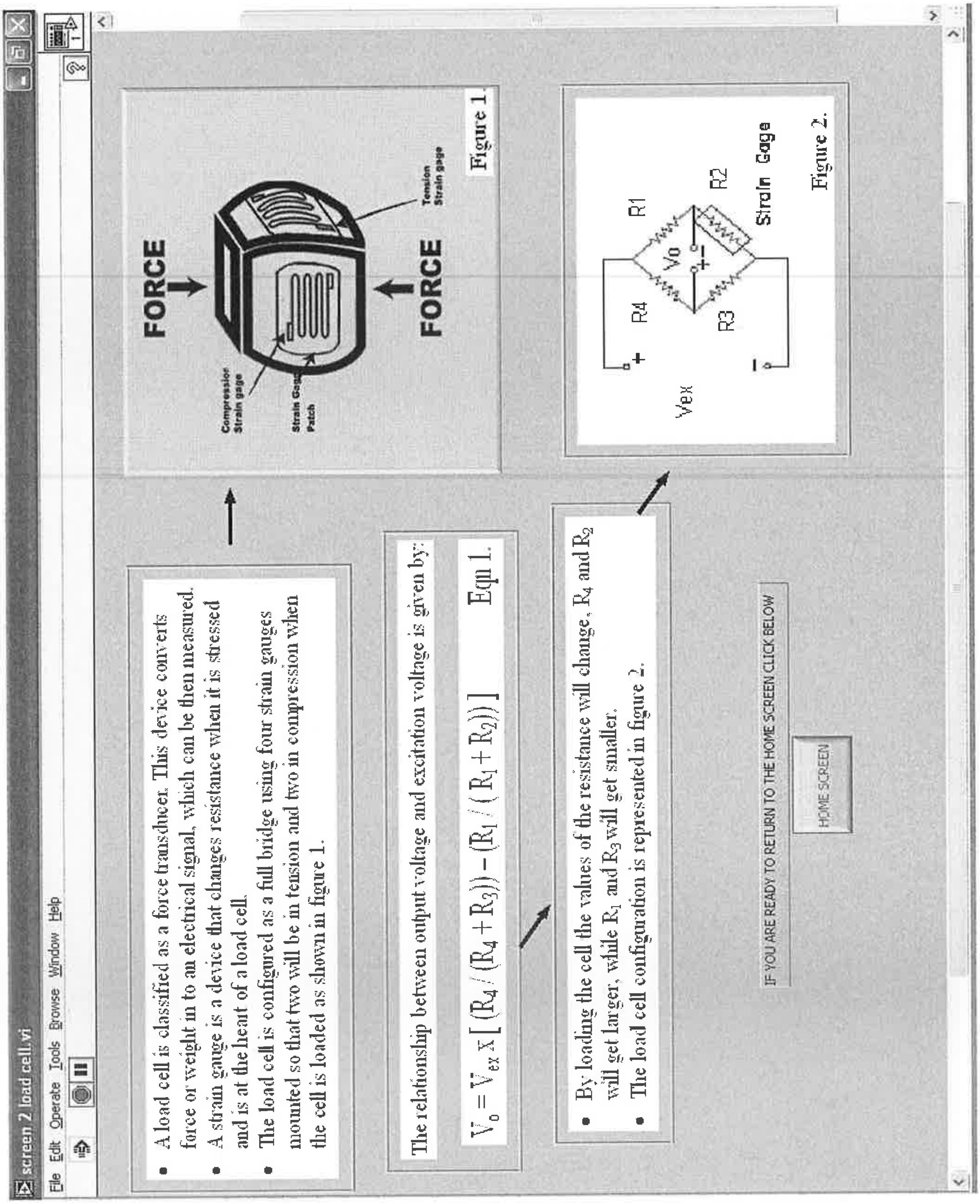
A 1.5 Load Cell Experiment



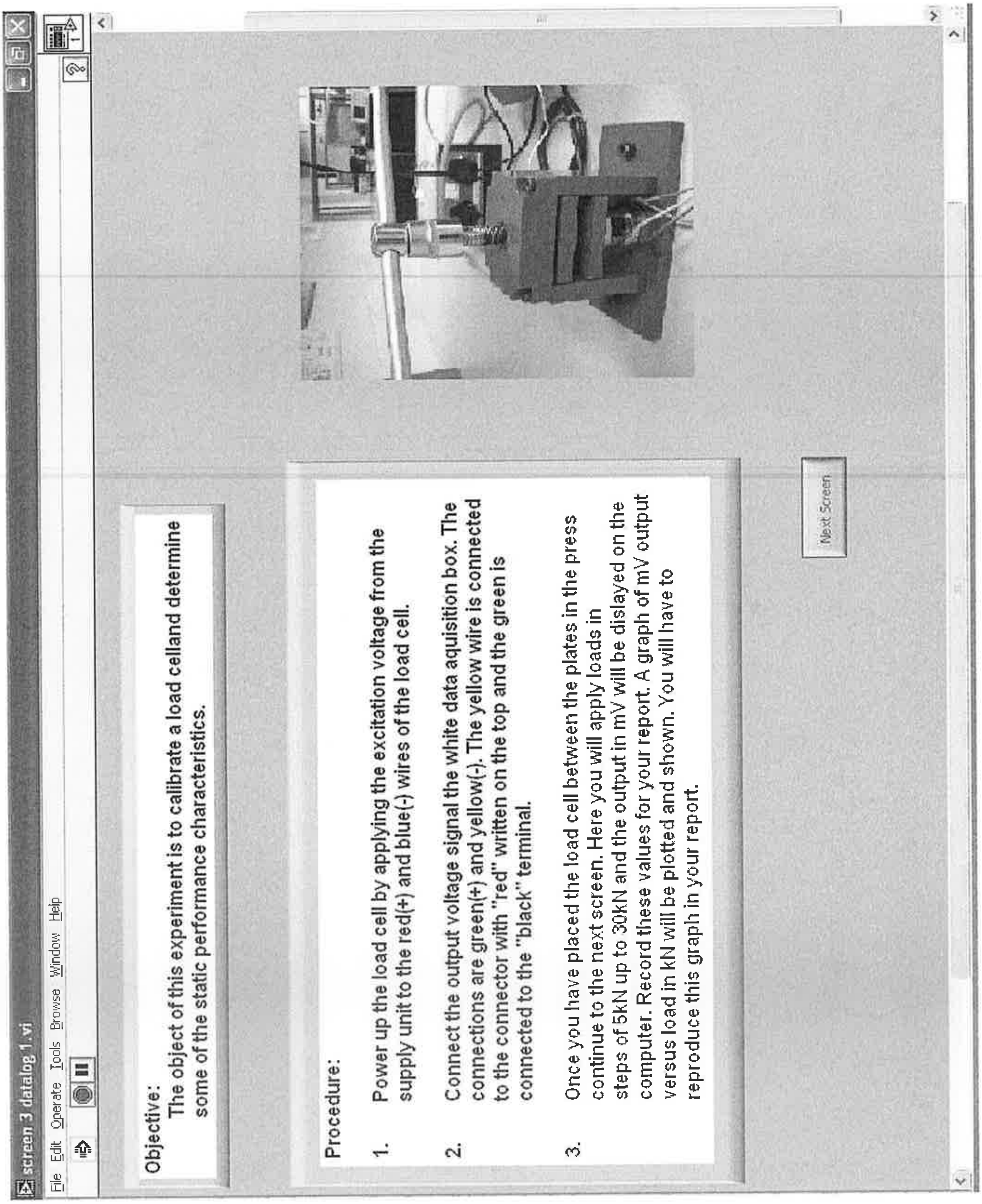
A1.34 Home Screen for Load Cell Experiment



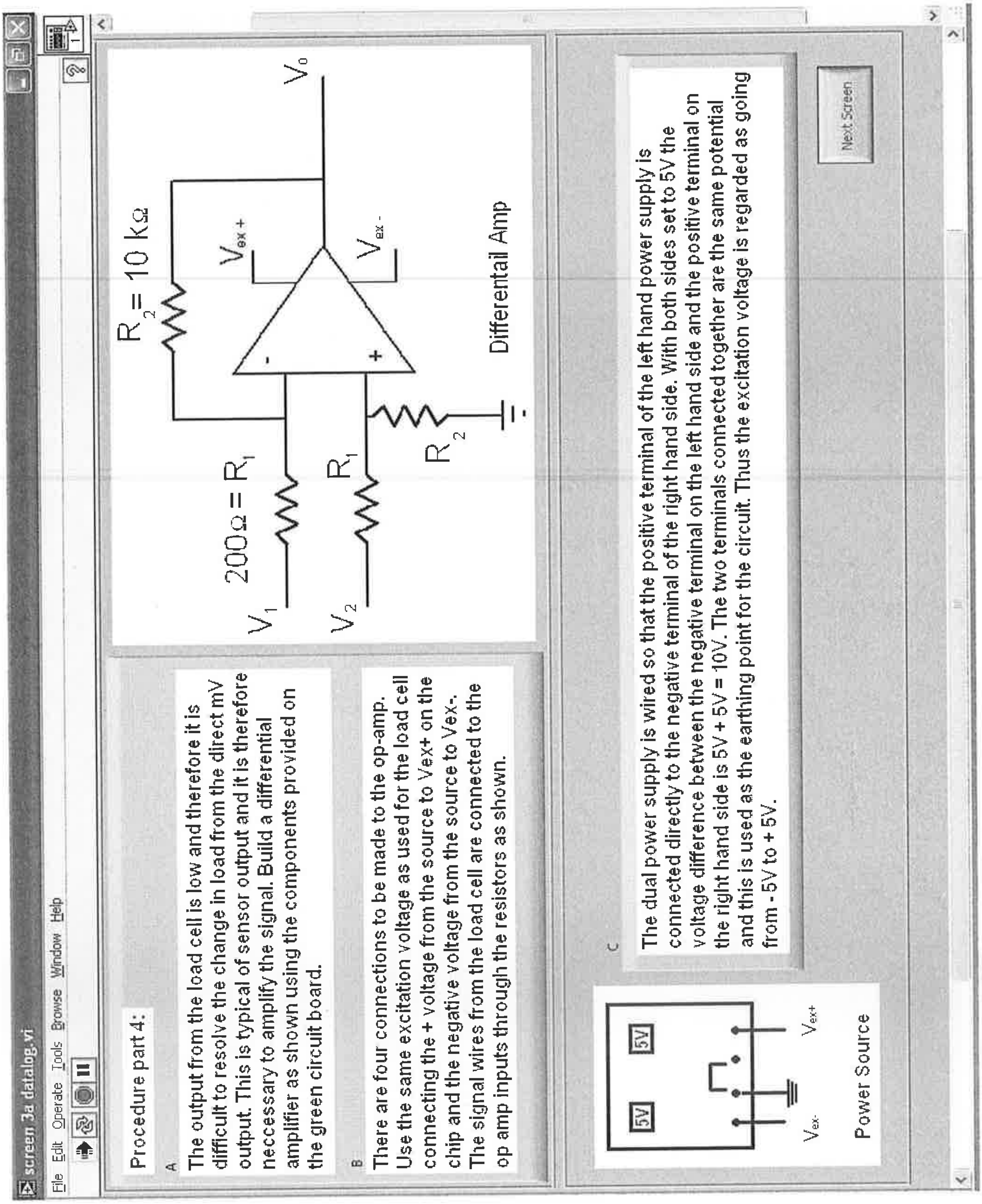
A1.35 Theory and Animation Screen One for Load Cell Experiment



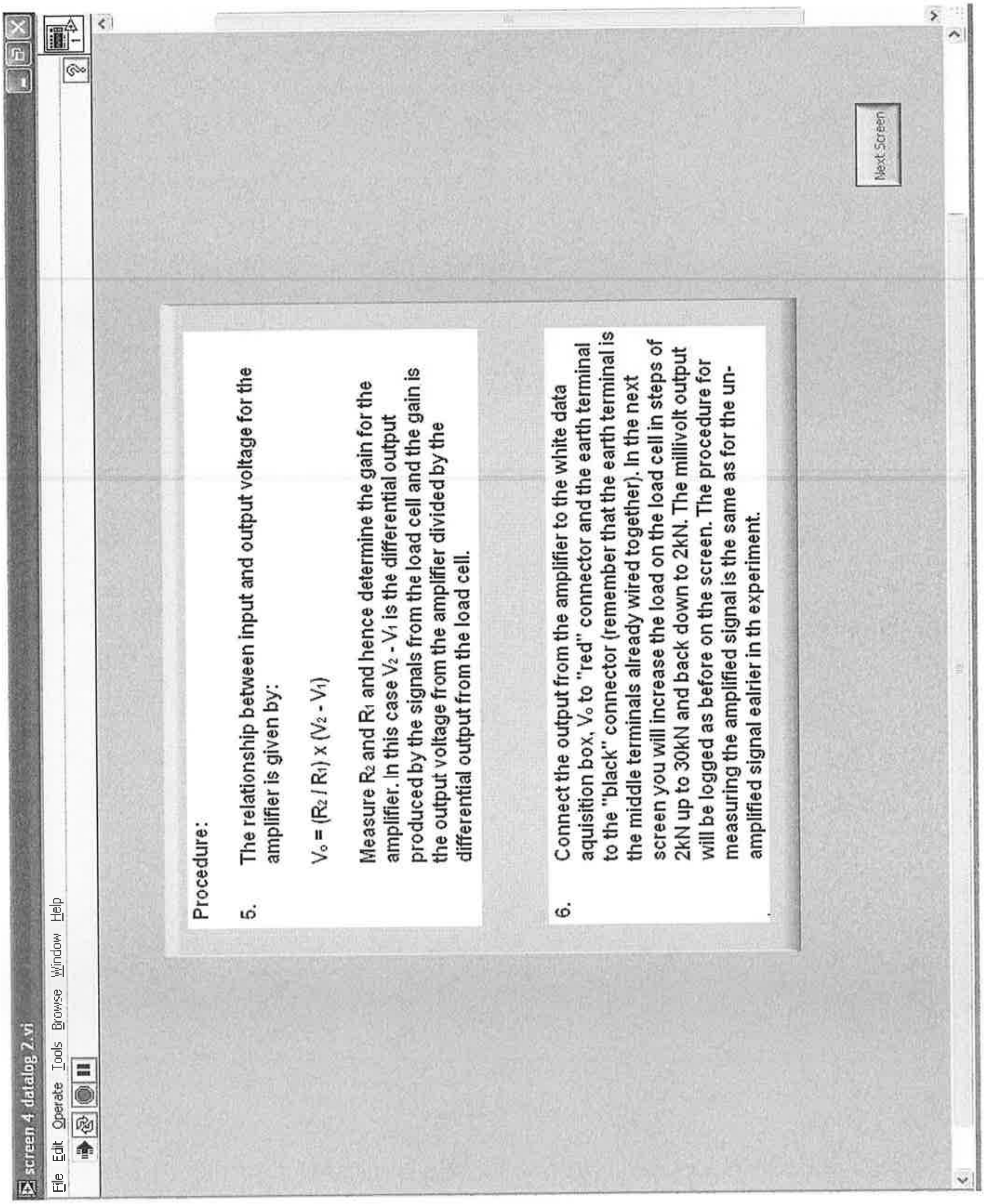
A1.36 Theory and Animation Screen Two for Load Cell Experiment



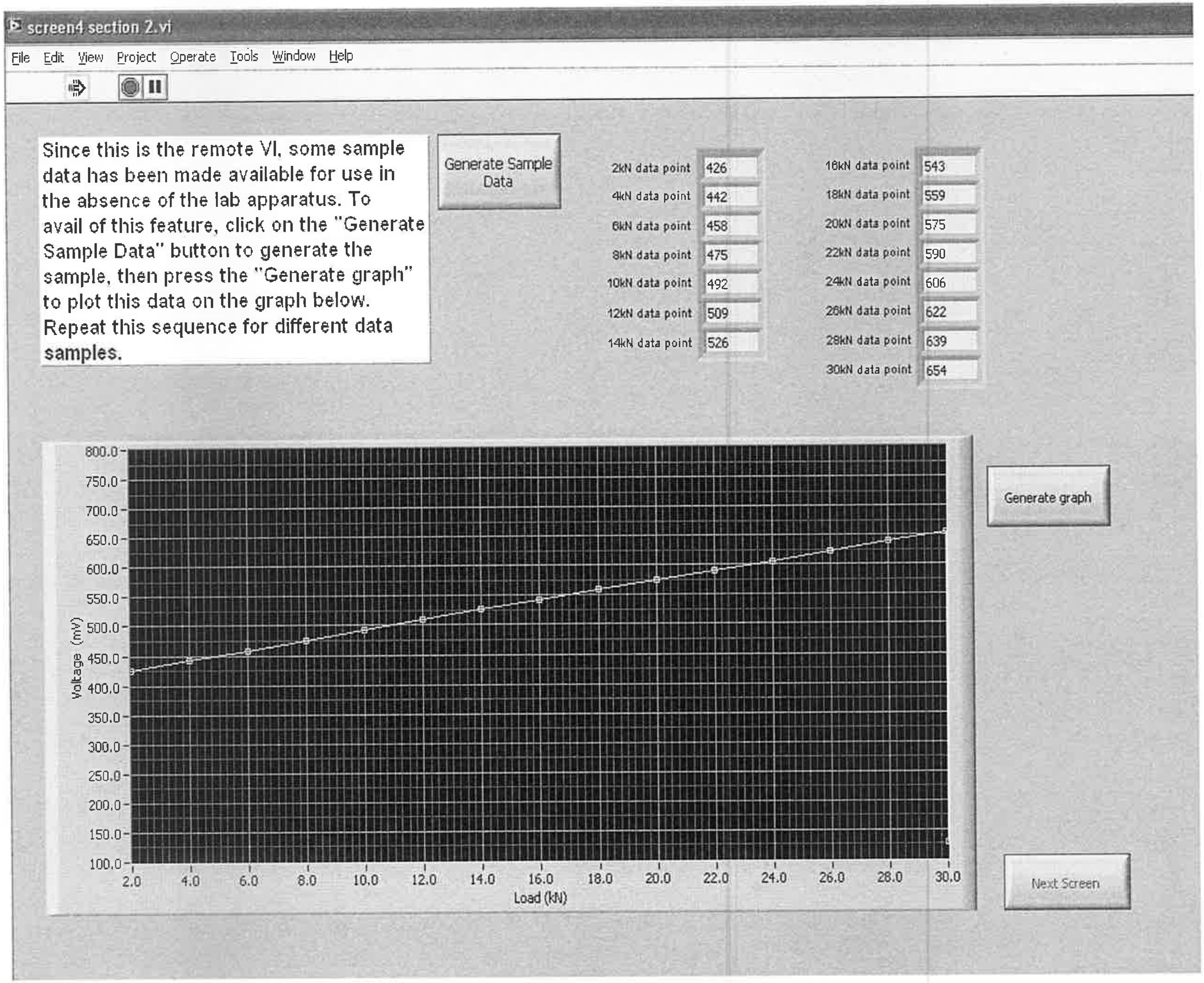
A1.37 Procedure and Data Logging Screen One for Load Cell Experiment



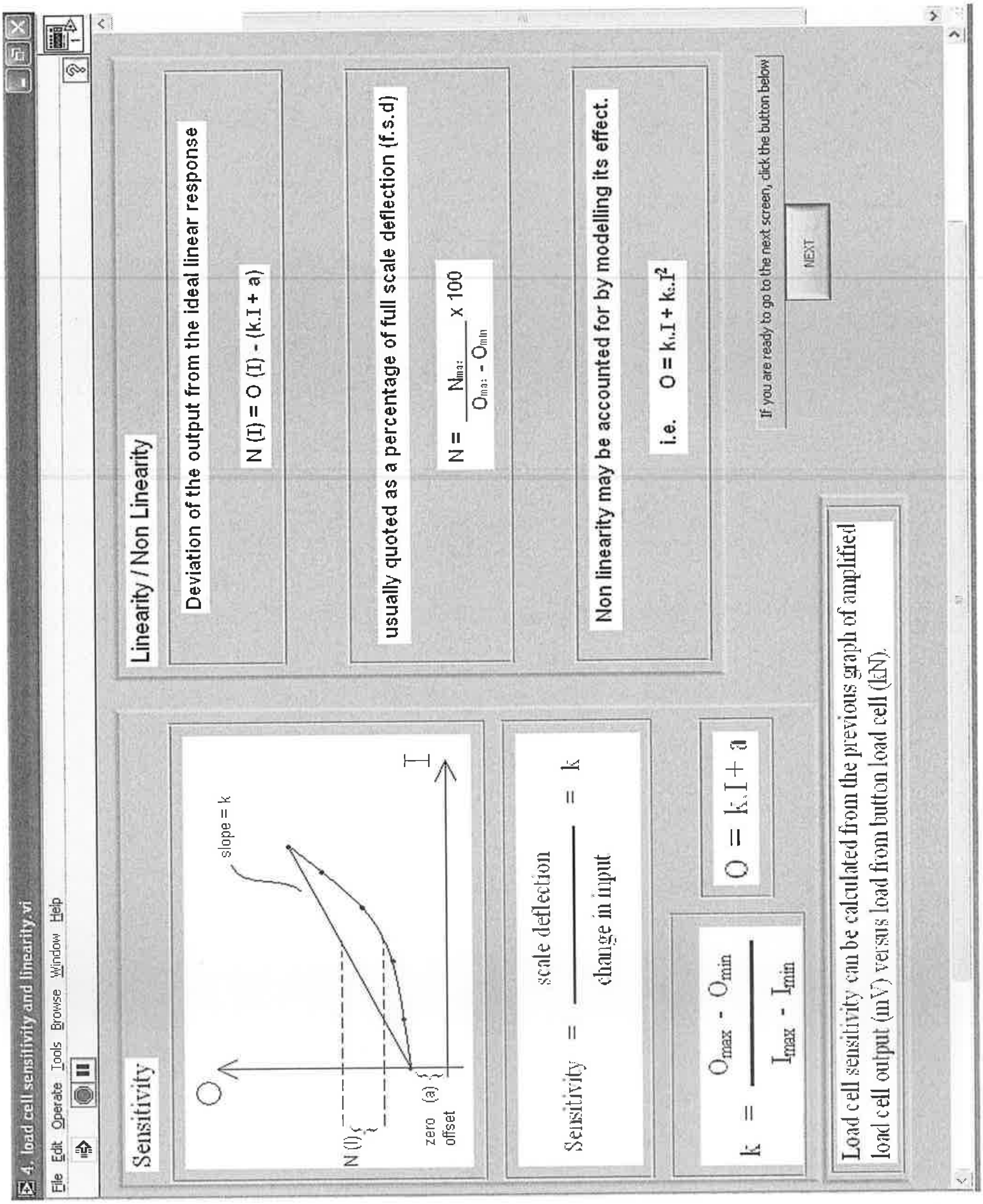
A1.38 Procedure and Data Logging Screen Two for Load Cell Experiment



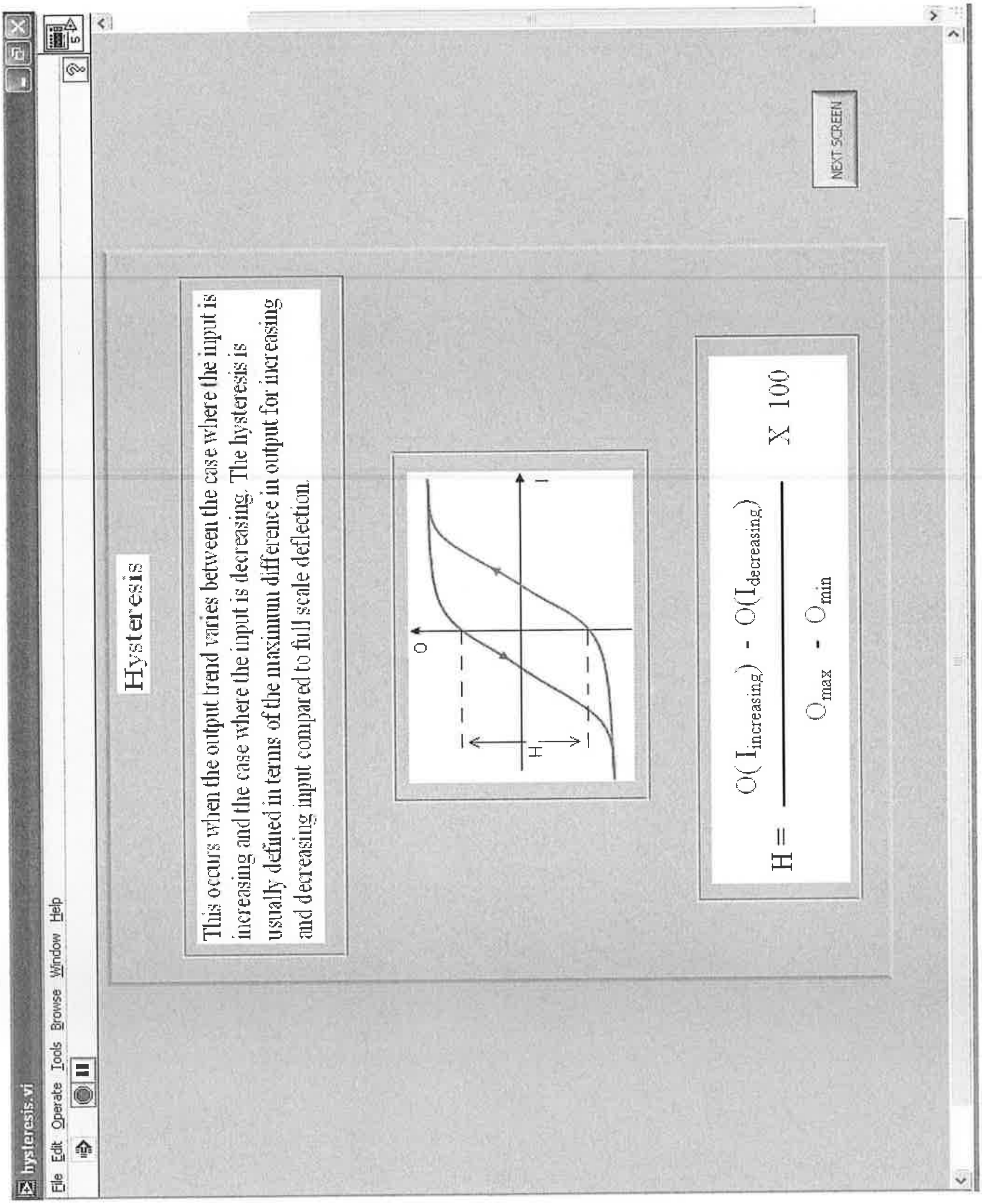
A1.39 Procedure and Data Logging Screen Three for Load Cell Experiment



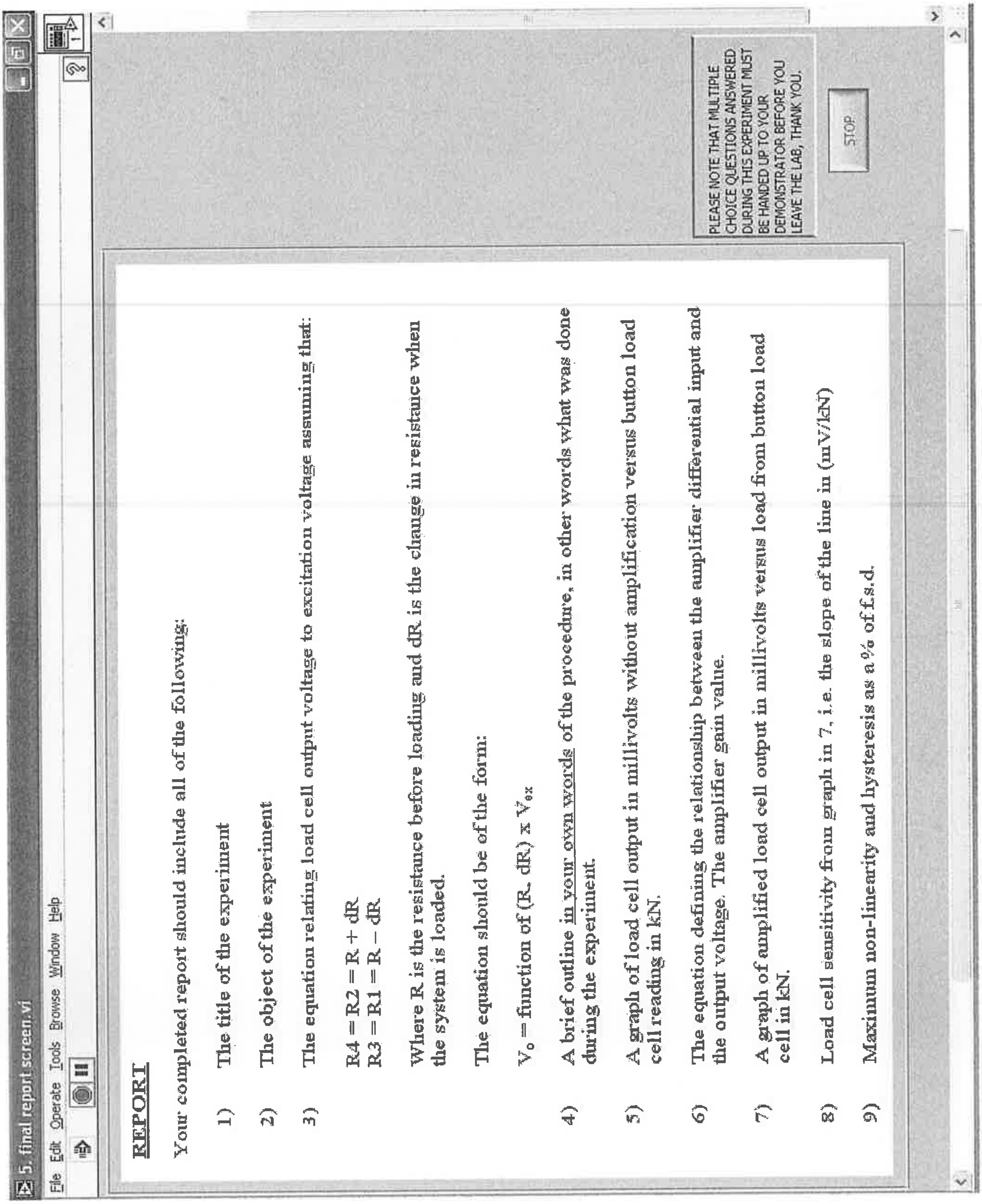
A1.40 Procedure and Data Logging Screen Four for Load Cell Experiment



A1.41 Theory and Calculation Screen One for Load Cell Experiment

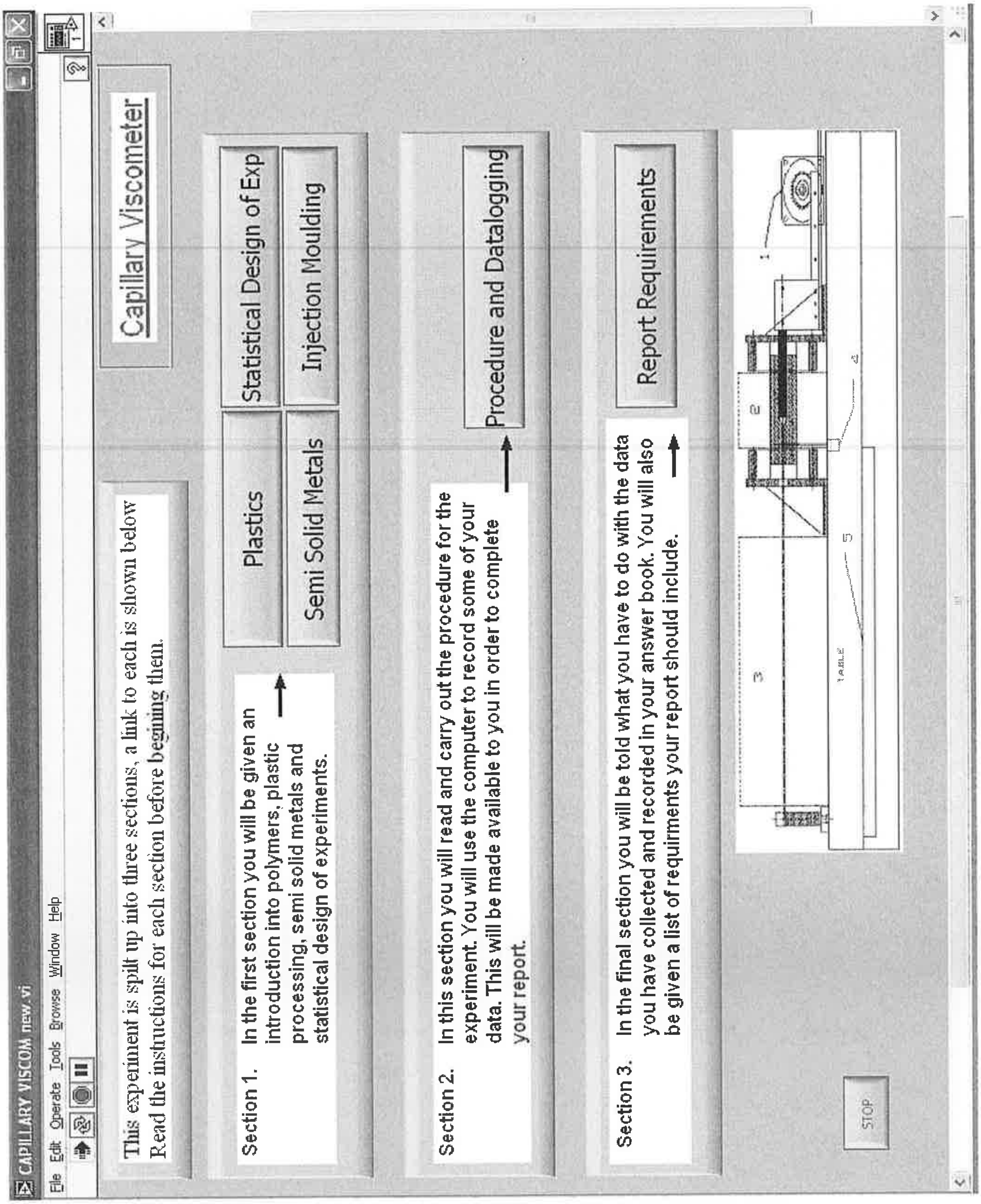


A1.42 Theory and Calculation Screen Two for Load Cell Experiment

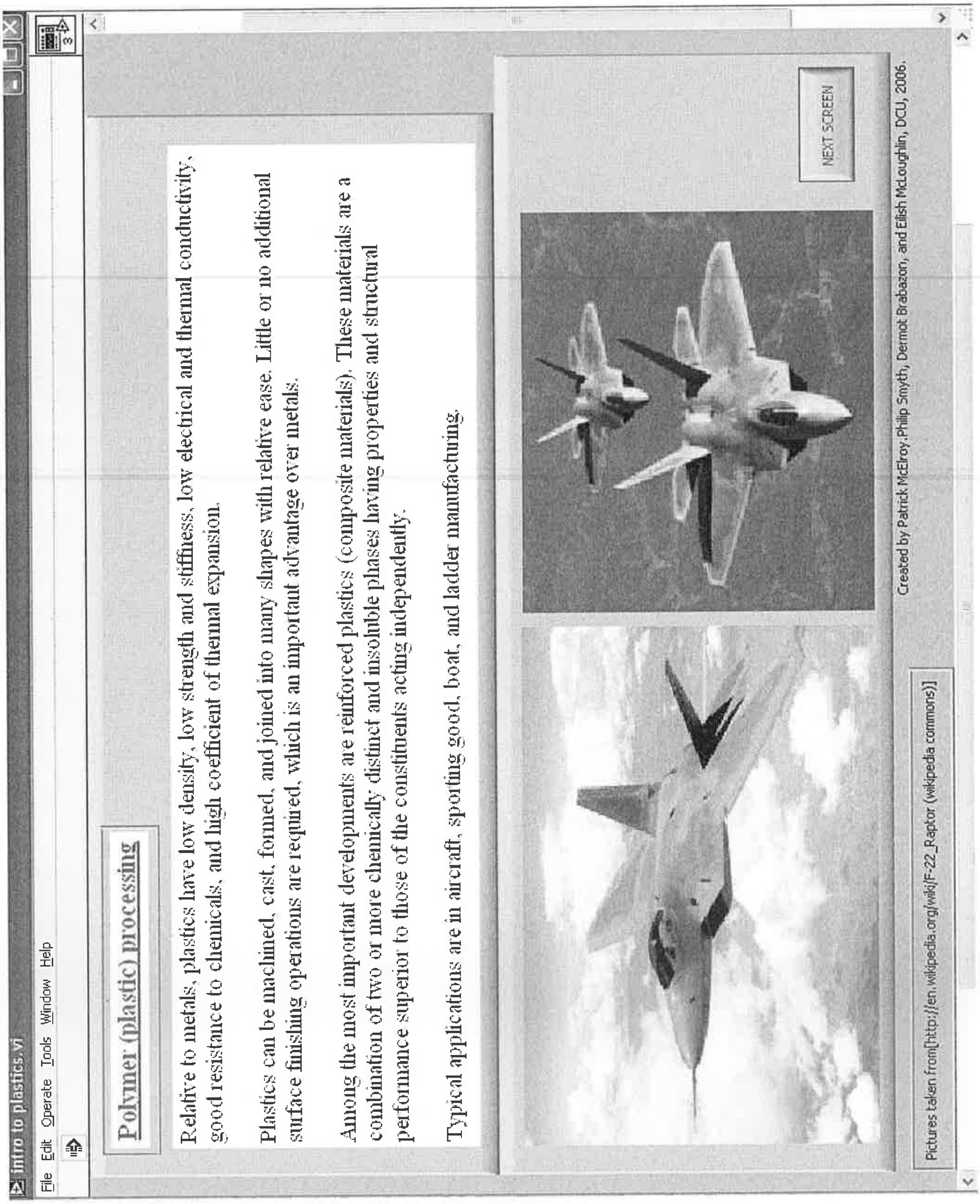


A1.43 Report Requirements Screen for Load Cell Experiment

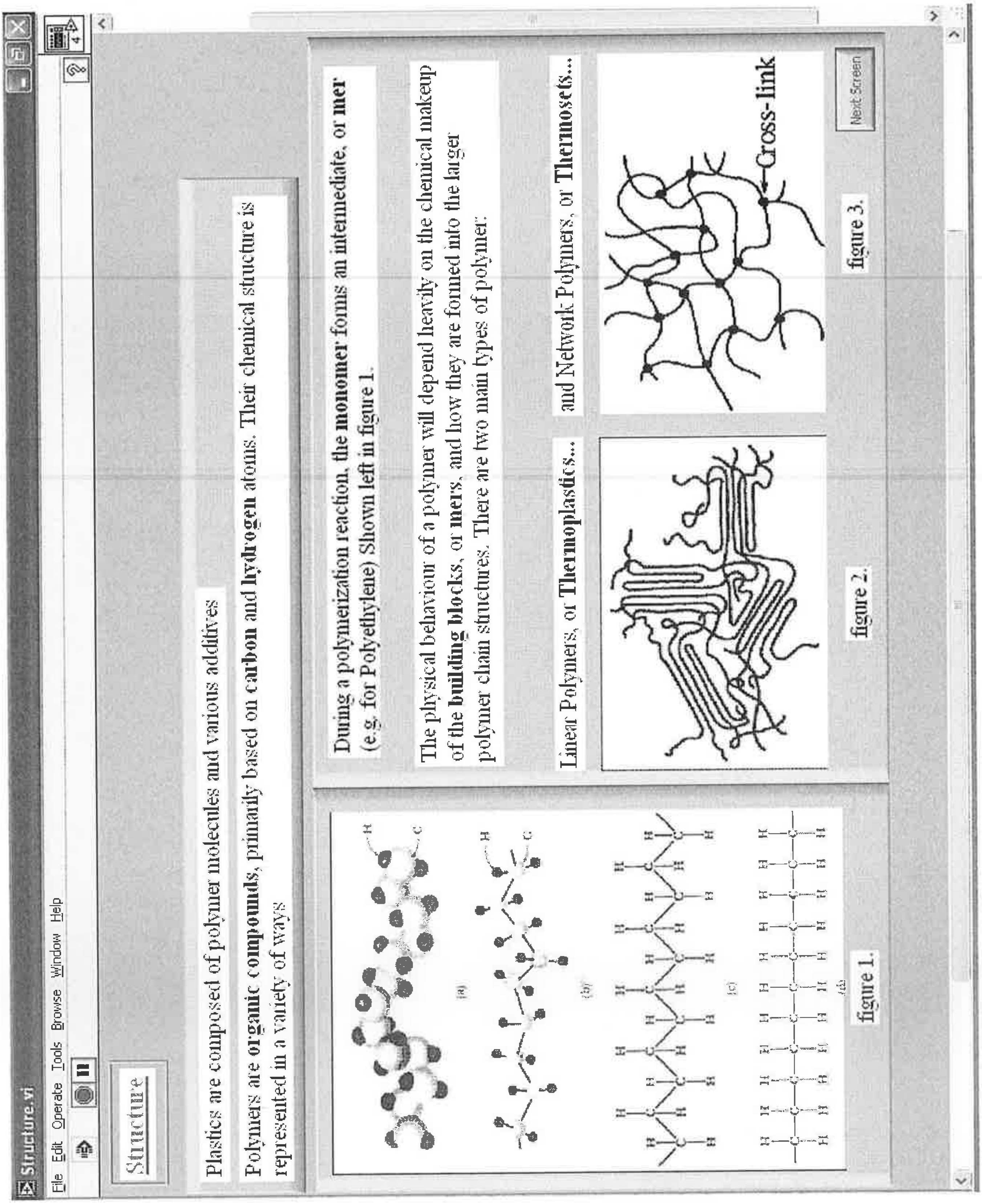
A 1.6 Capillary Viscometer Experiment



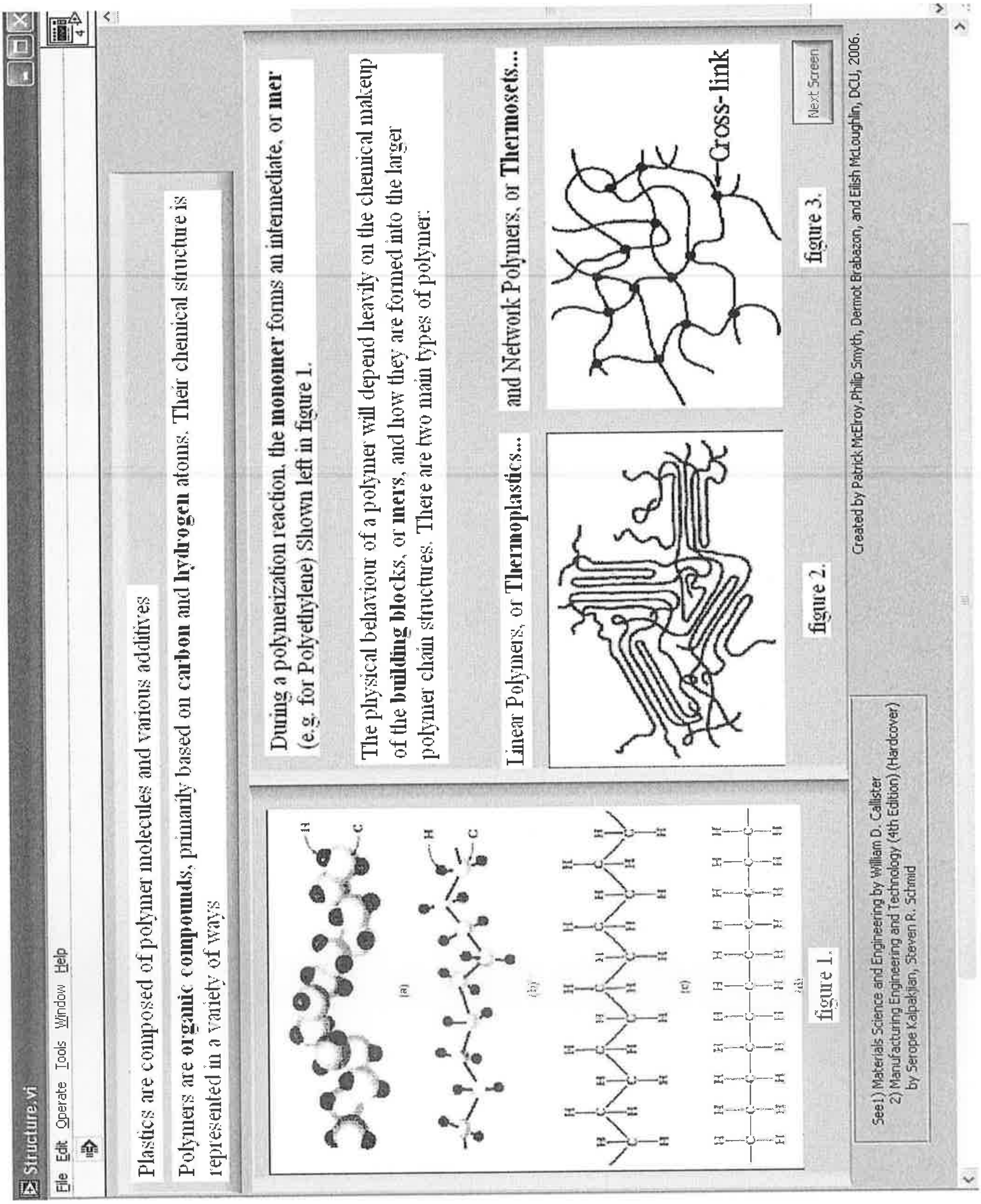
A1.44 Home Screen for Capillary Viscometer



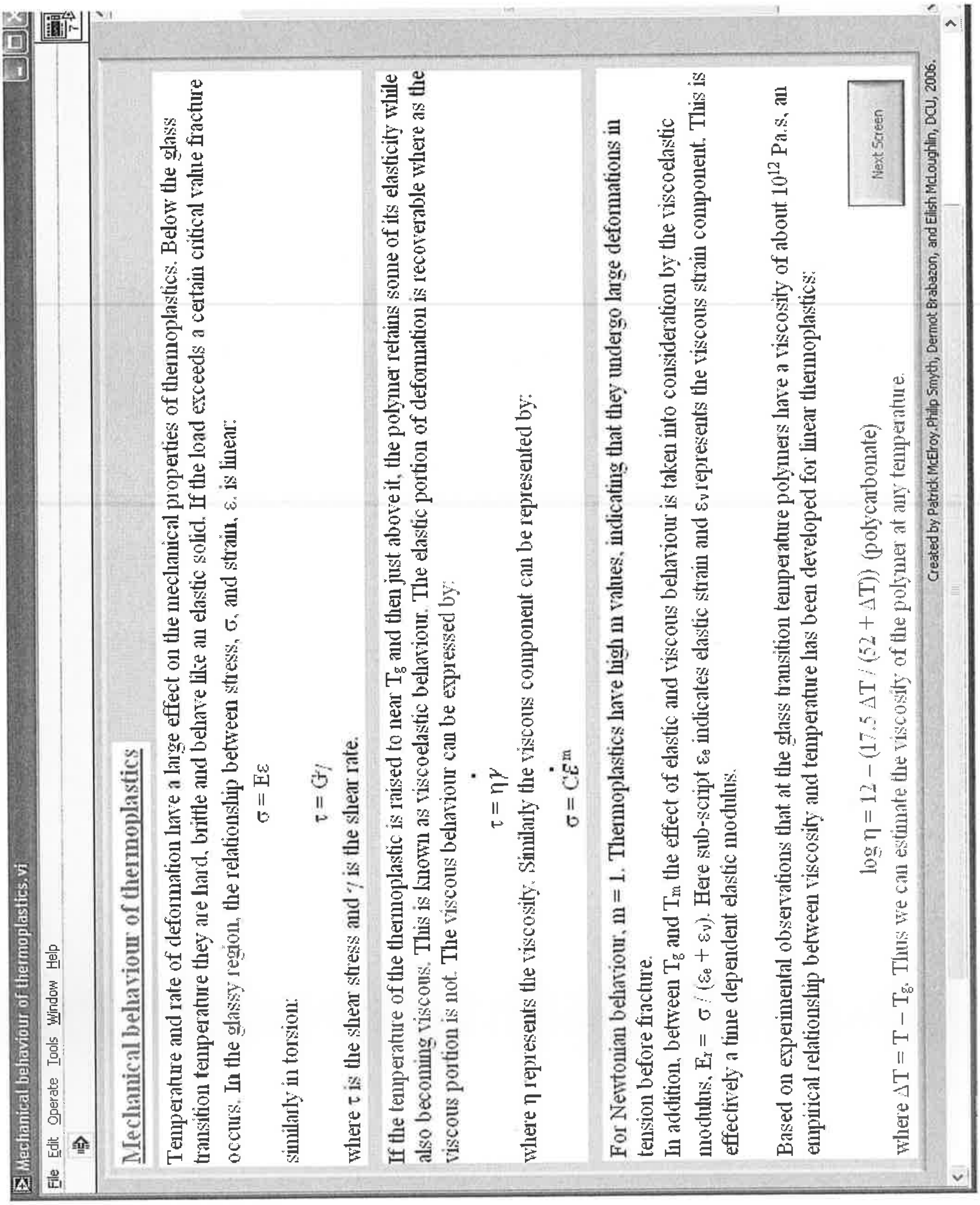
A1.45 Introduction Section, Plastics Screen One for Capillary Viscometer Experiment



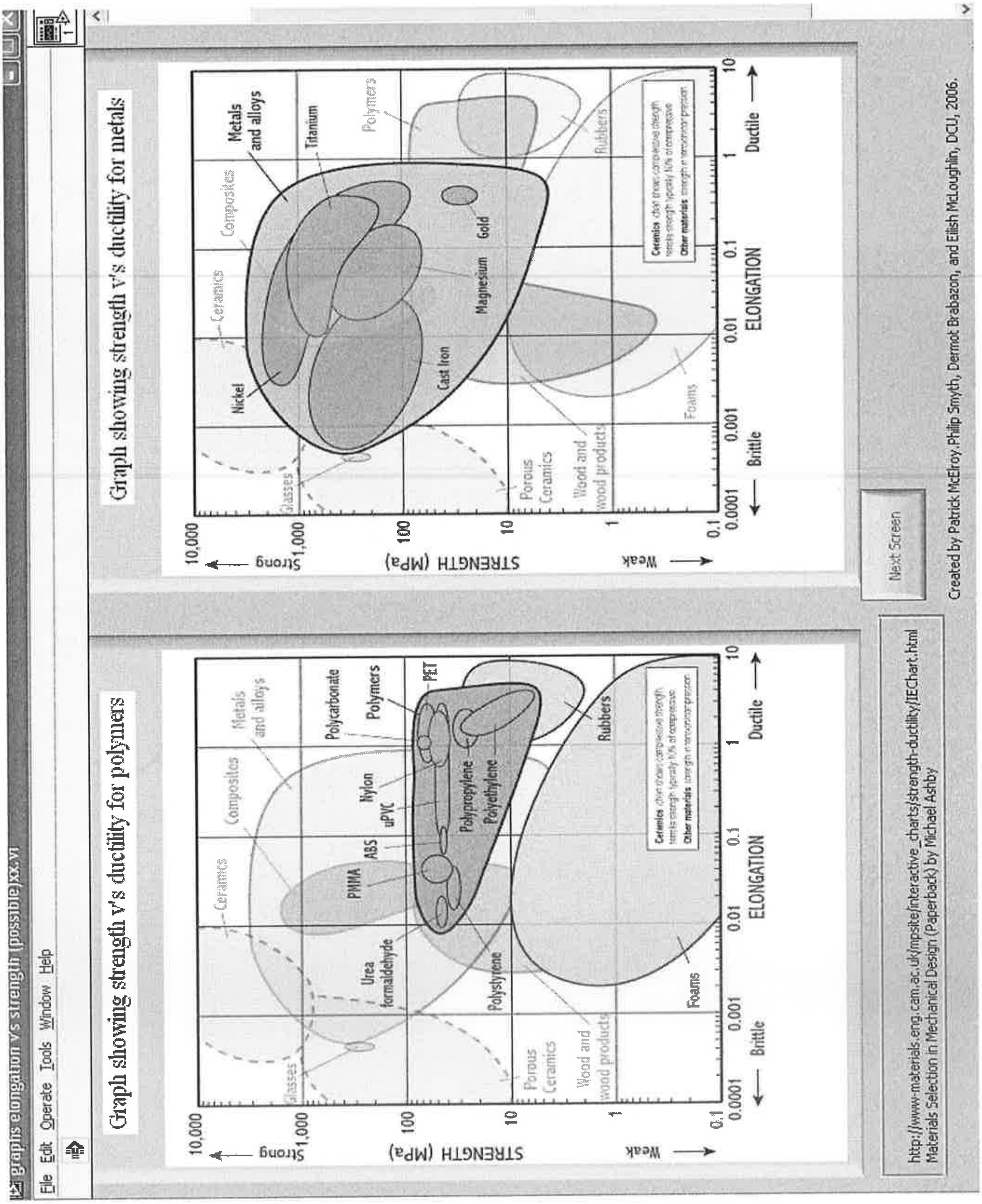
A1.46 Introduction Section, Plastics Screen Two for Capillary Viscometer Experiment



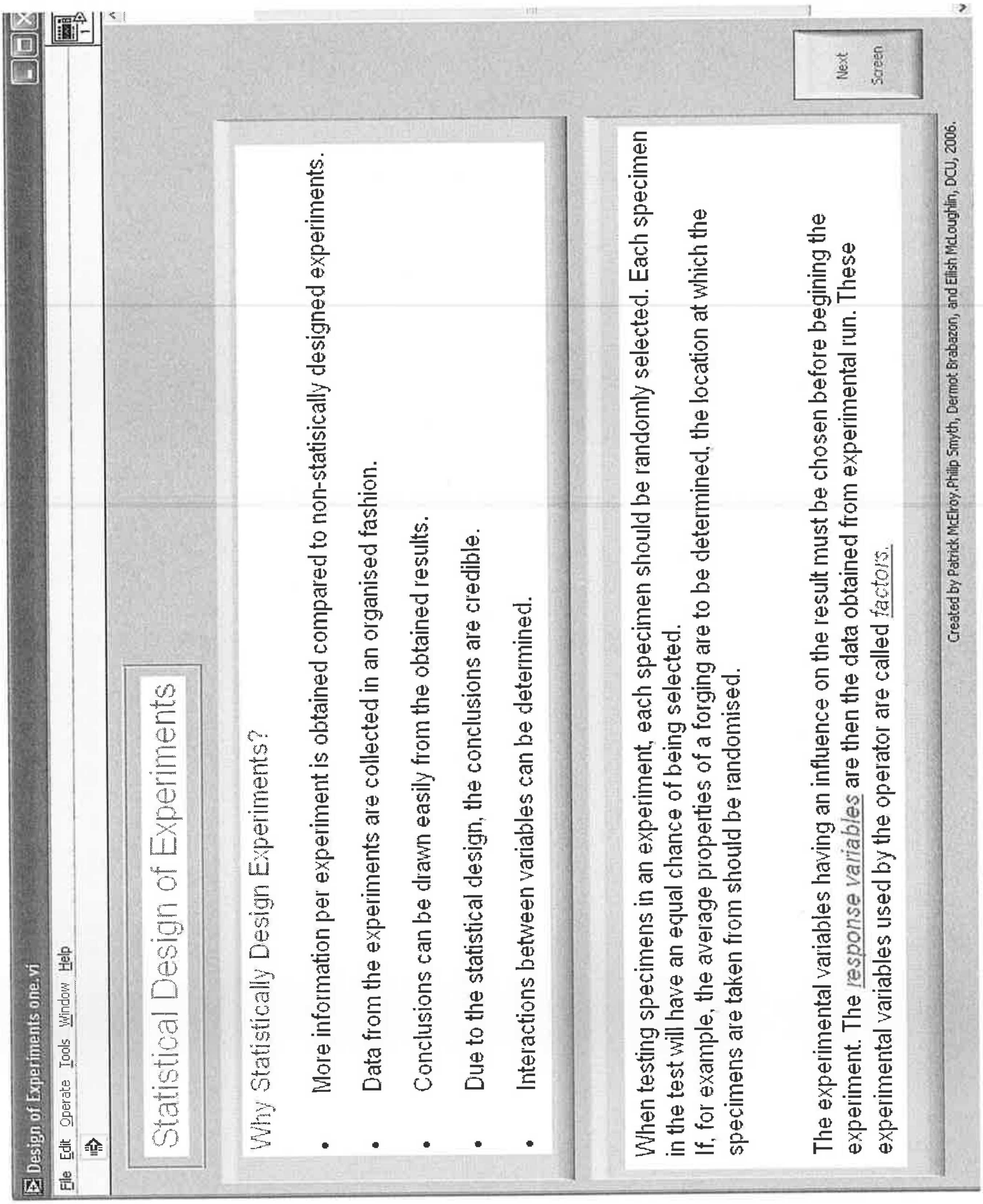
A1.47 Introduction Section, Plastics Screen Three for Capillary Viscometer Experiment



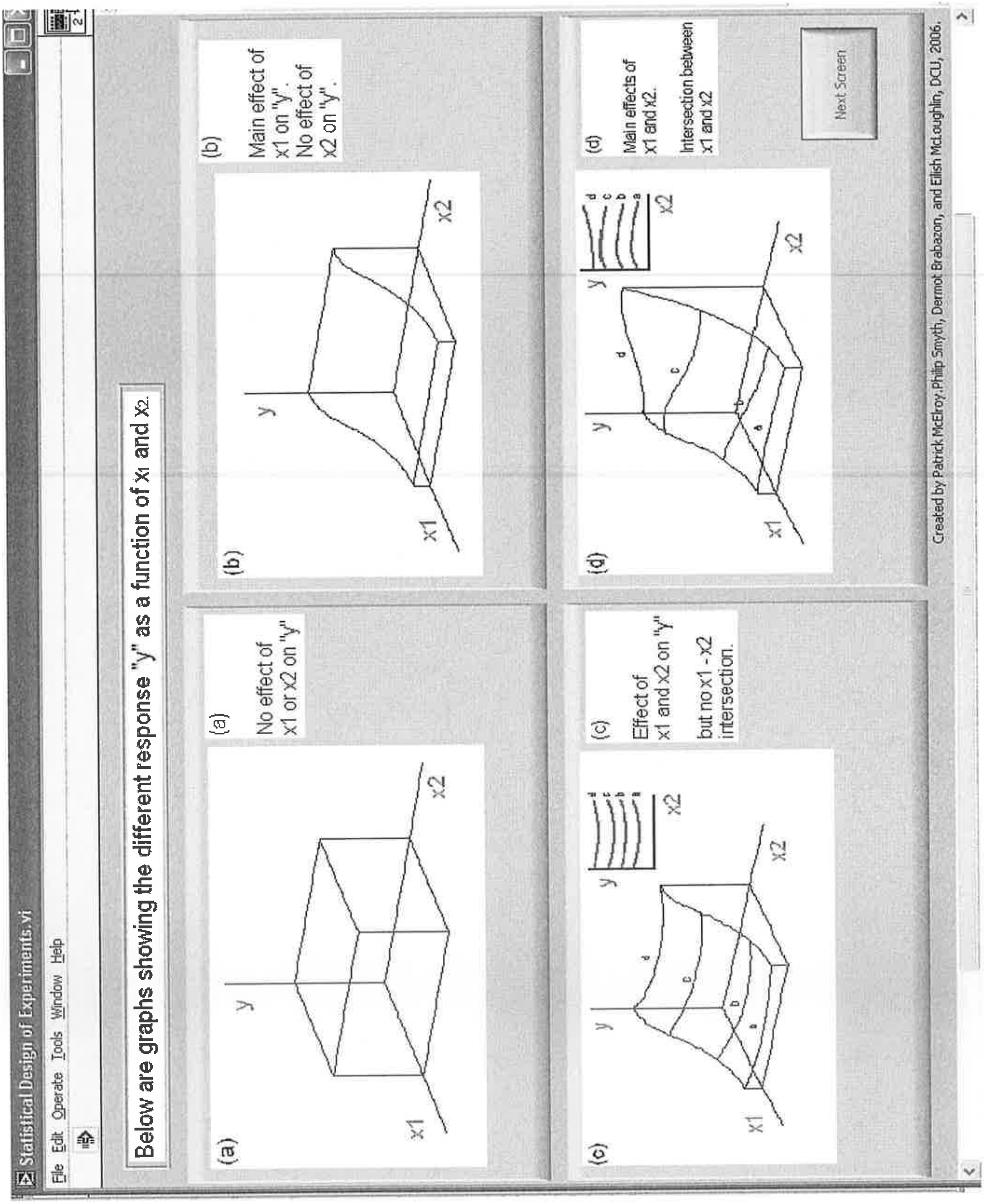
A1.48 Introduction Section, Plastics Screen Four for Capillary Viscometer Experiment



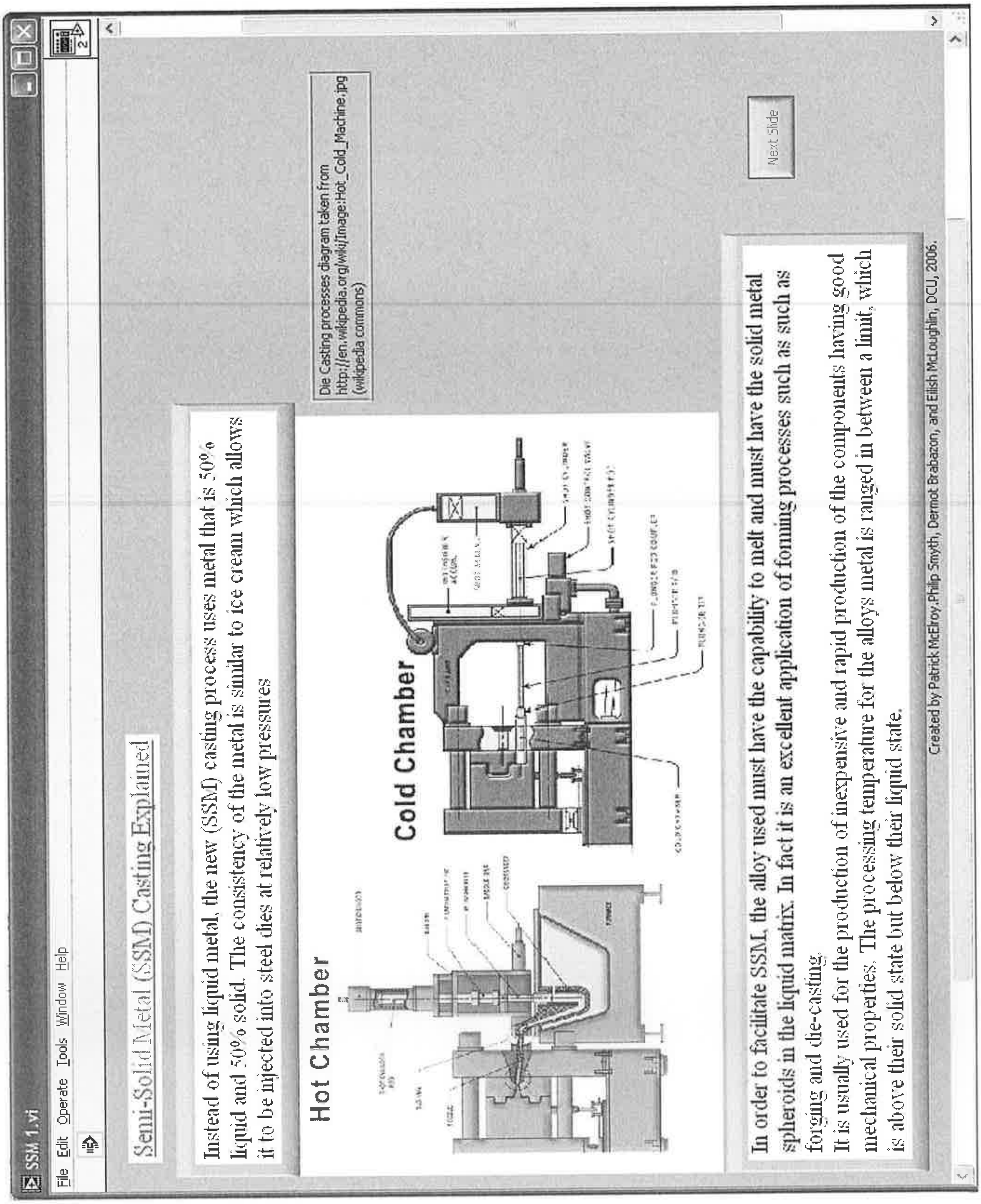
A1.49 Introduction Section, Plastics Screen Five for Capillary Viscometer Experiment



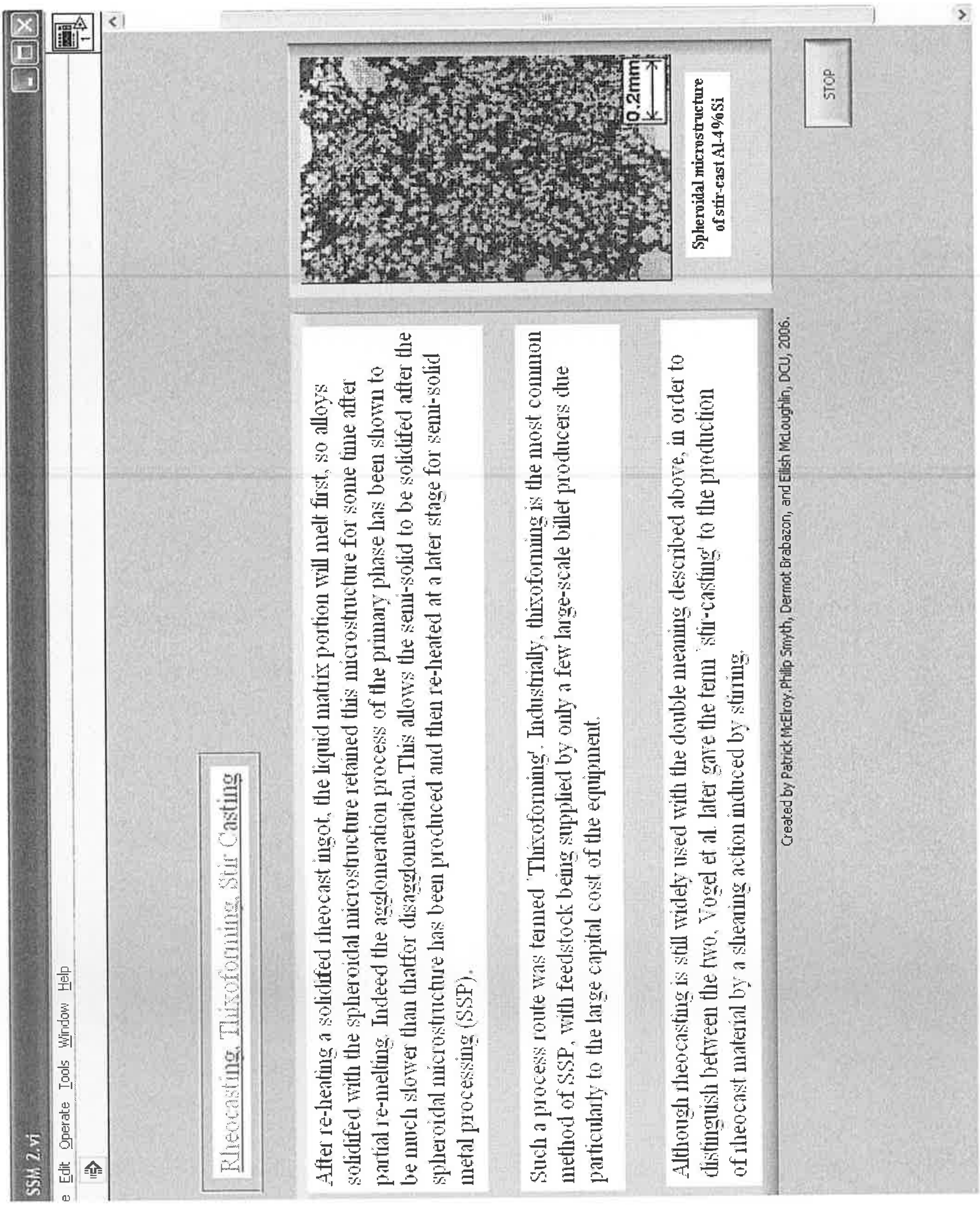
A1.50 Introduction Section, Design of Experiments Screen One for Capillary Viscometer Experiment



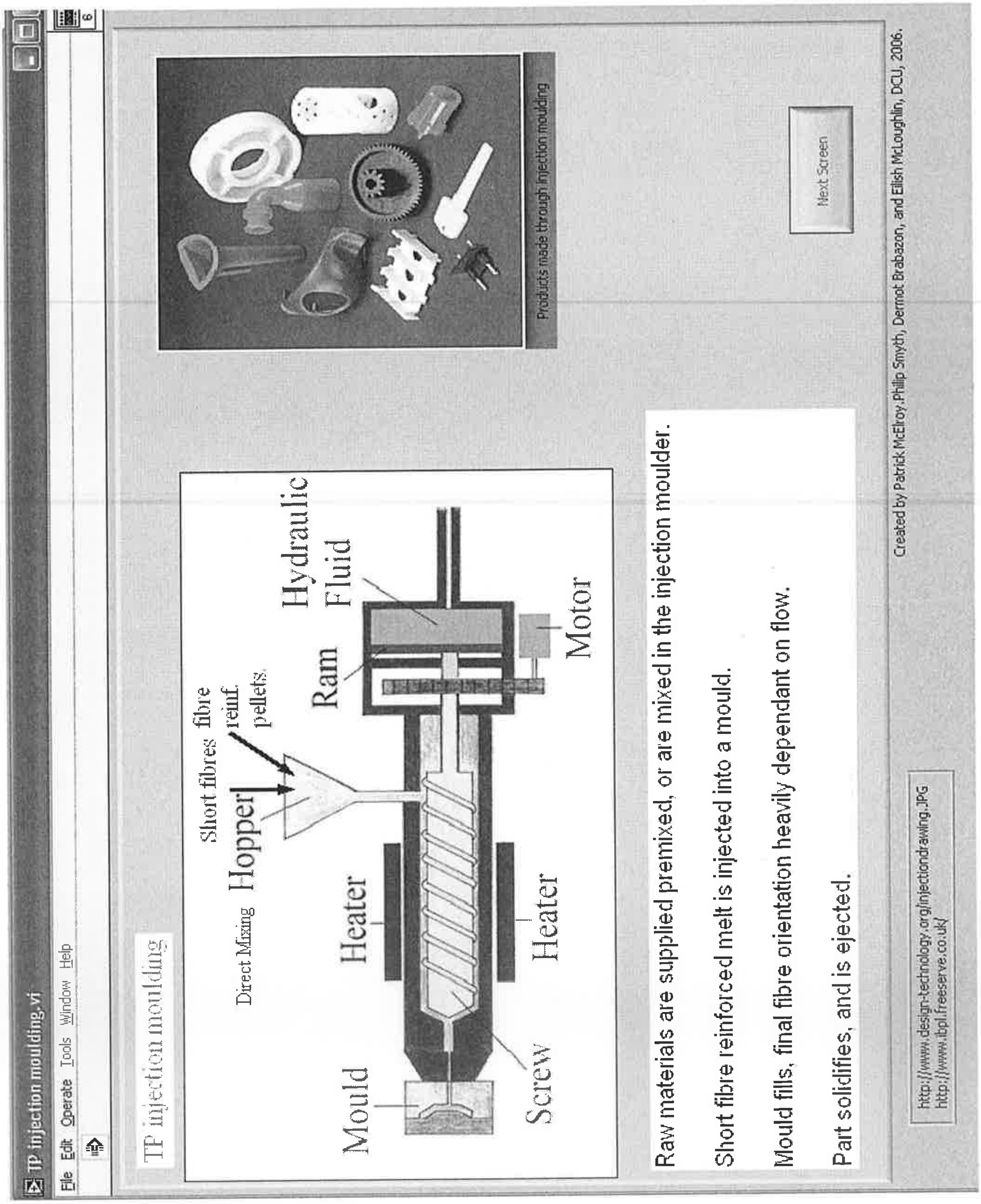
A1.51 Introduction Section, Design of Experiments Screen Two for Capillary Viscometer Experiment



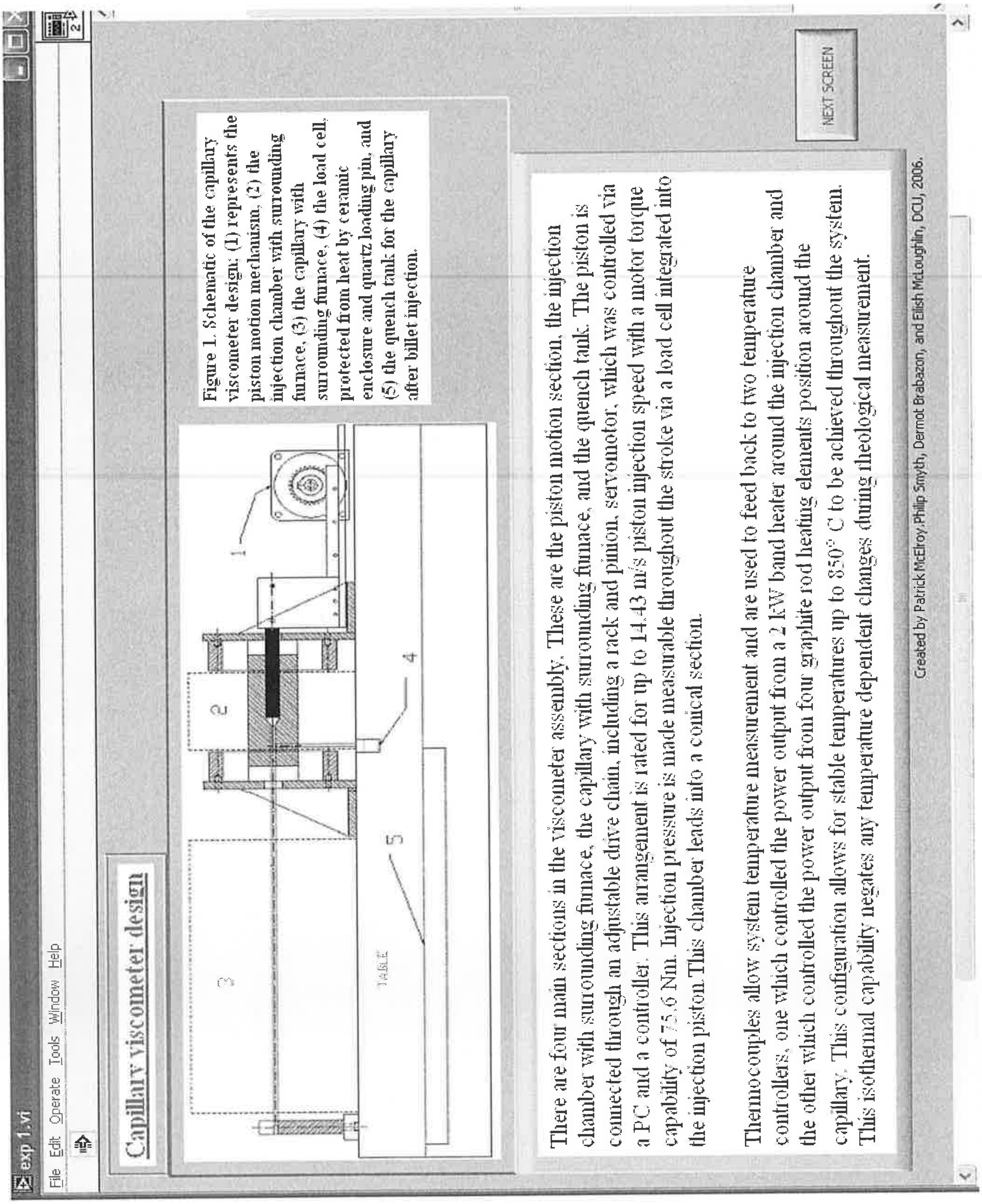
A1.52 Introduction Section, Semi-Solid Metals Screen One for Capillary Viscometer Experiment



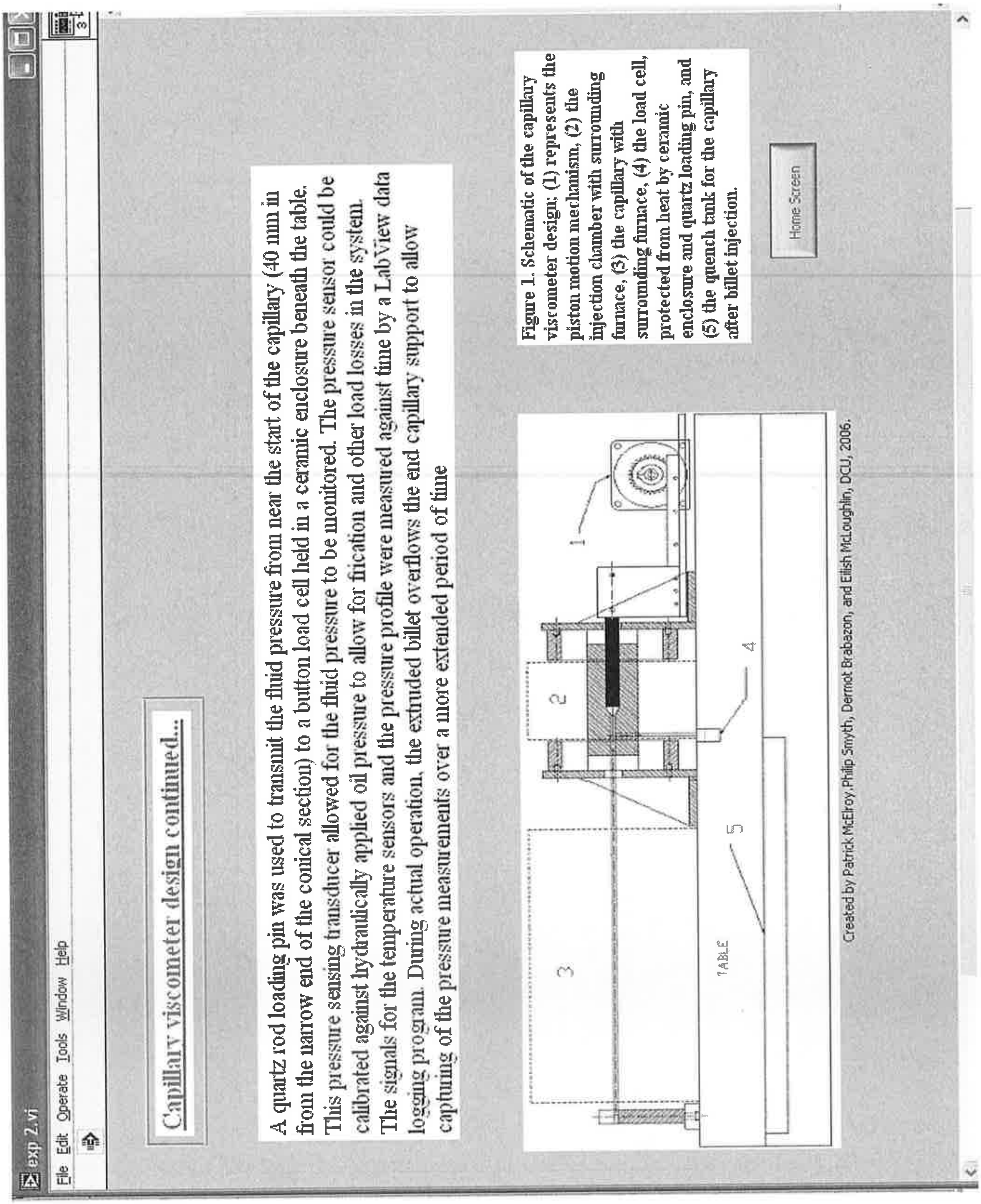
A1.53 Introduction Section, Design of Experiments Screen Two for Capillary Viscometer Experiment



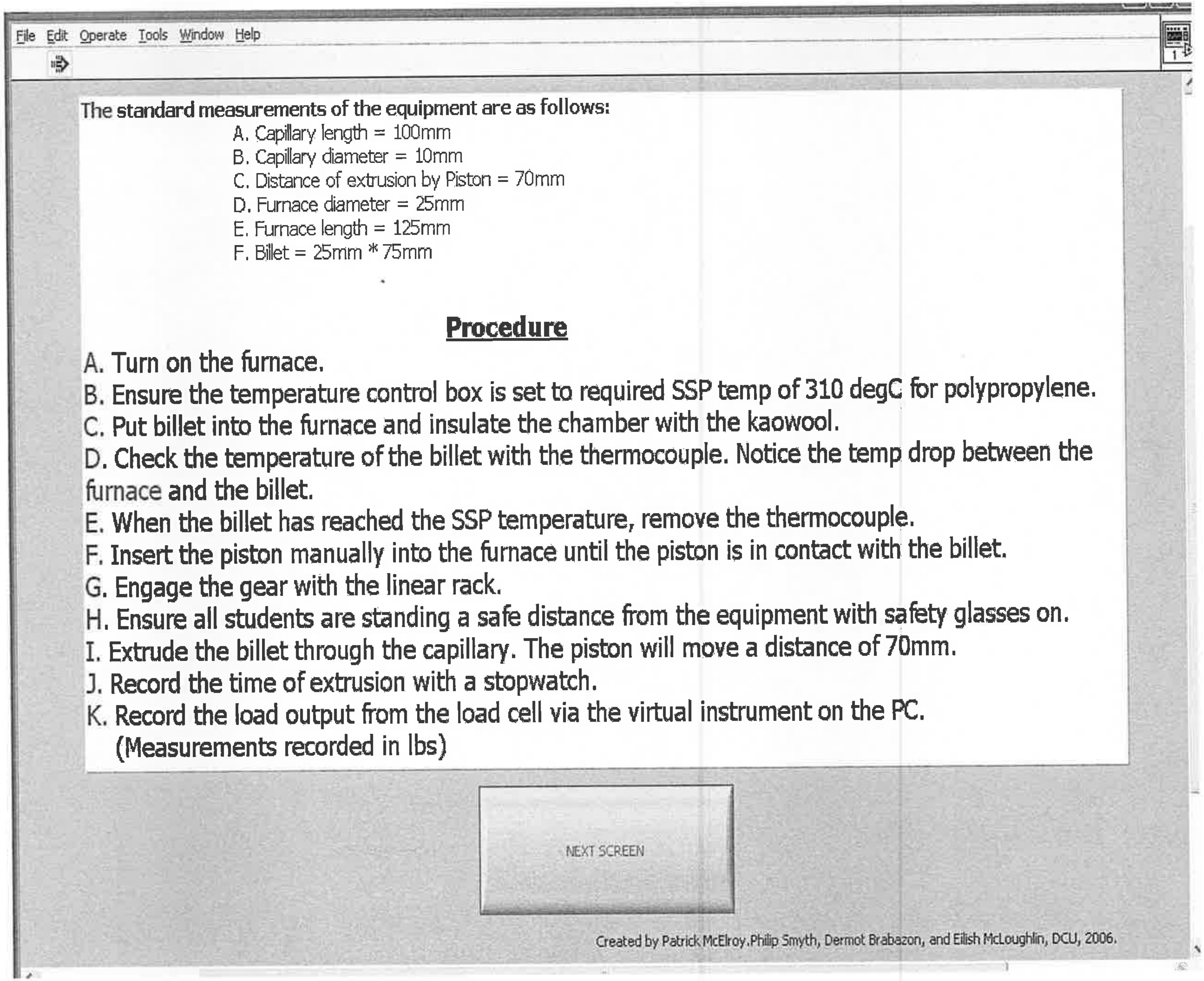
A1.54 Introduction Section, Injection Moulding Screen One for Capillary Viscometer Experiment



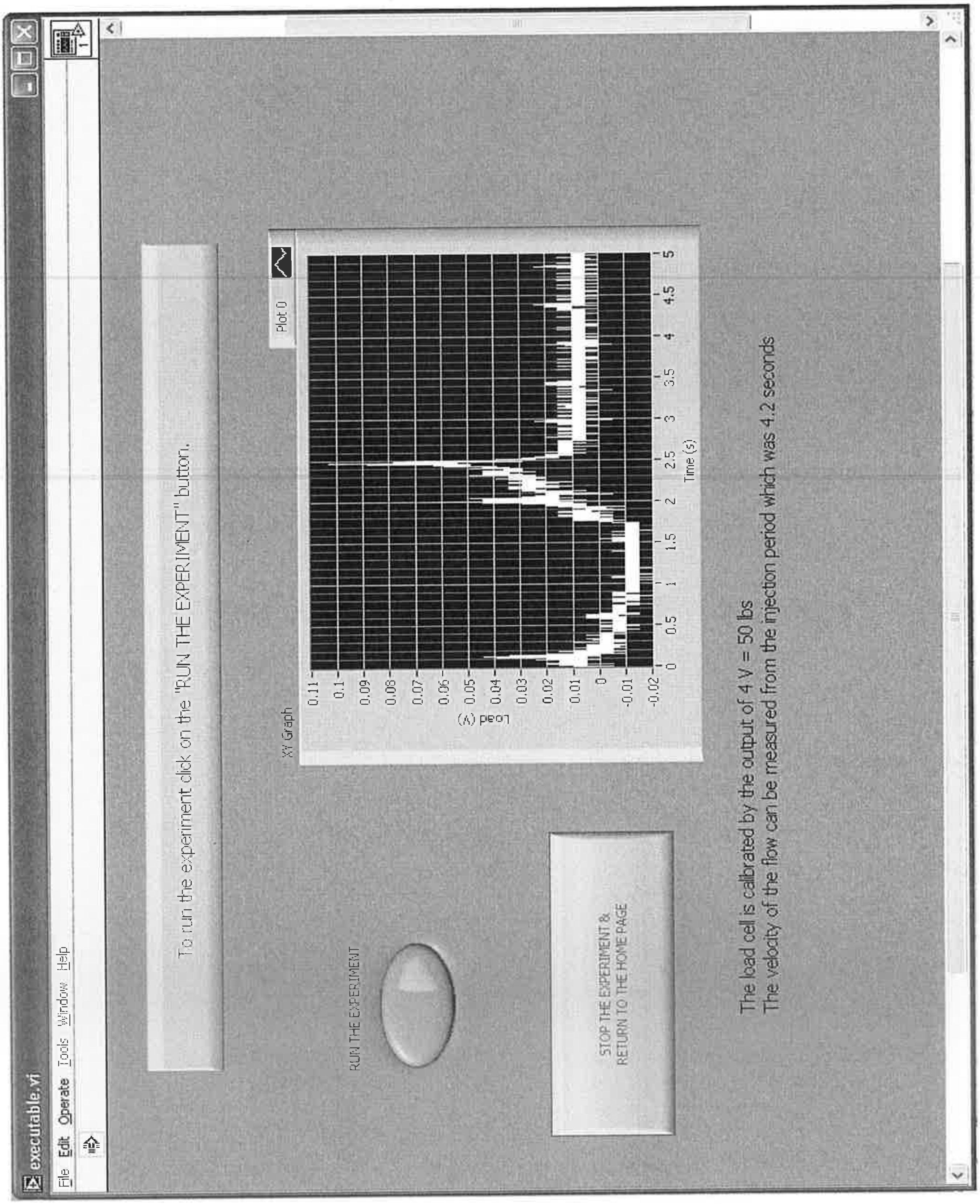
A1.55 Introduction Section, Injection Moulding Screen Two for Capillary Viscometer Experiment



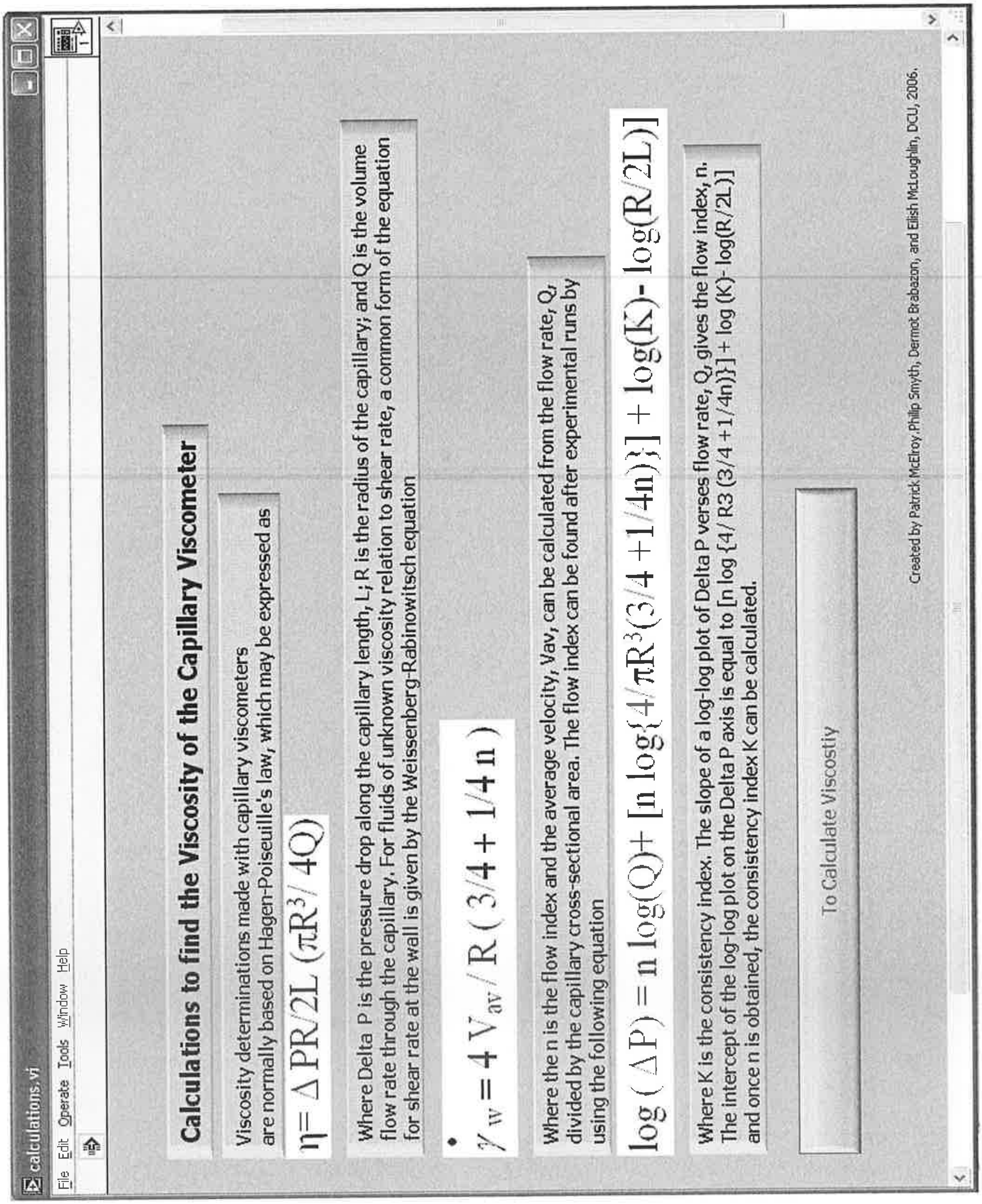
A1.56 Introduction Section, Injection Moulding Screen Three for Capillary Viscometer Experiment



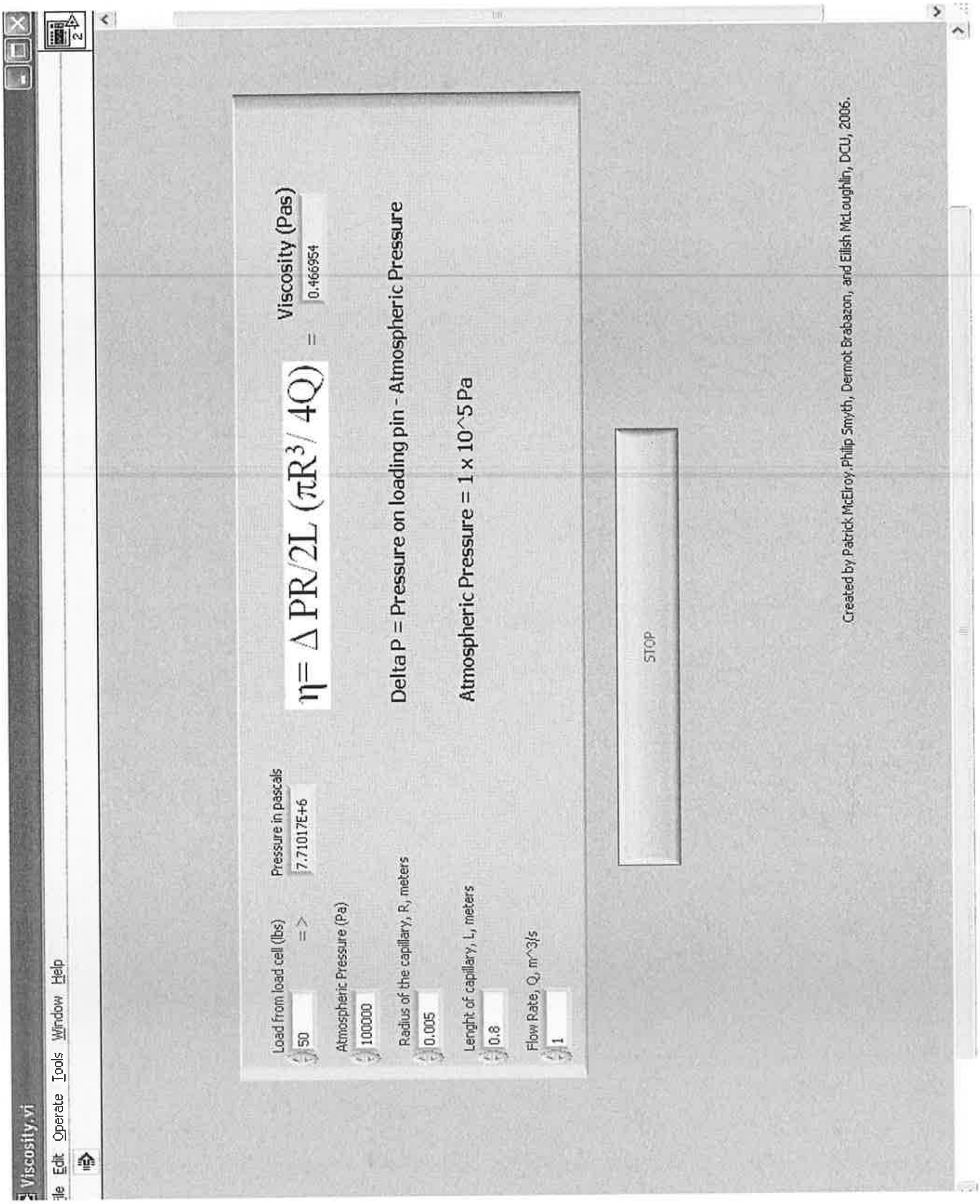
A1.57 Procedure and Data Logging Screen One for Capillary Viscometer Experiment



A1.58 Procedure and Data Logging Screen Two for Capillary Viscometer Experiment



A1.59 Analysis and Theory Screen One for Capillary Viscometer Experiment



A1.60 Analysis and Theory Screen Two for Capillary Viscometer Experiment

A 2 Selected Block Diagrams

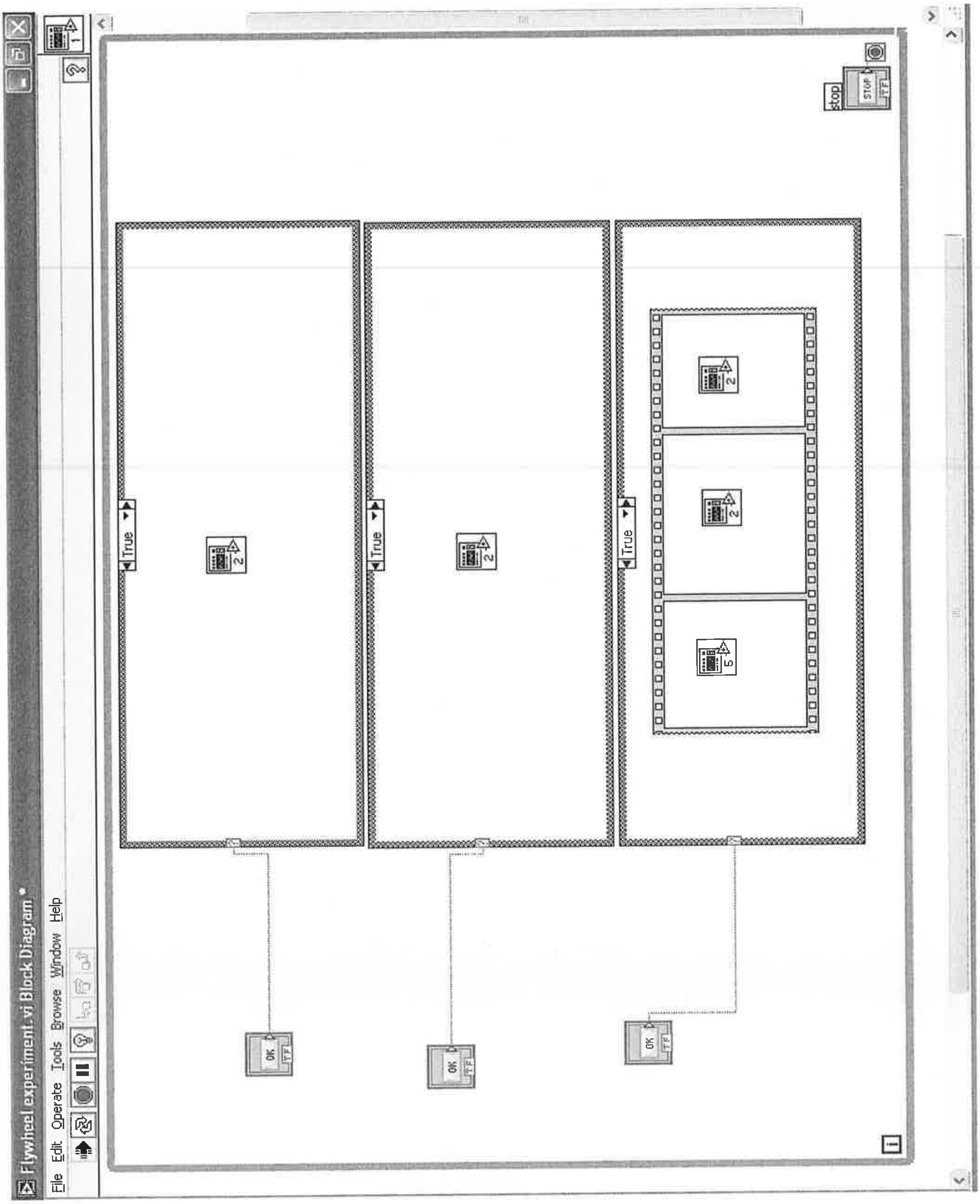


Figure A 2.1 Block diagram corresponding to the Flywheel home screen

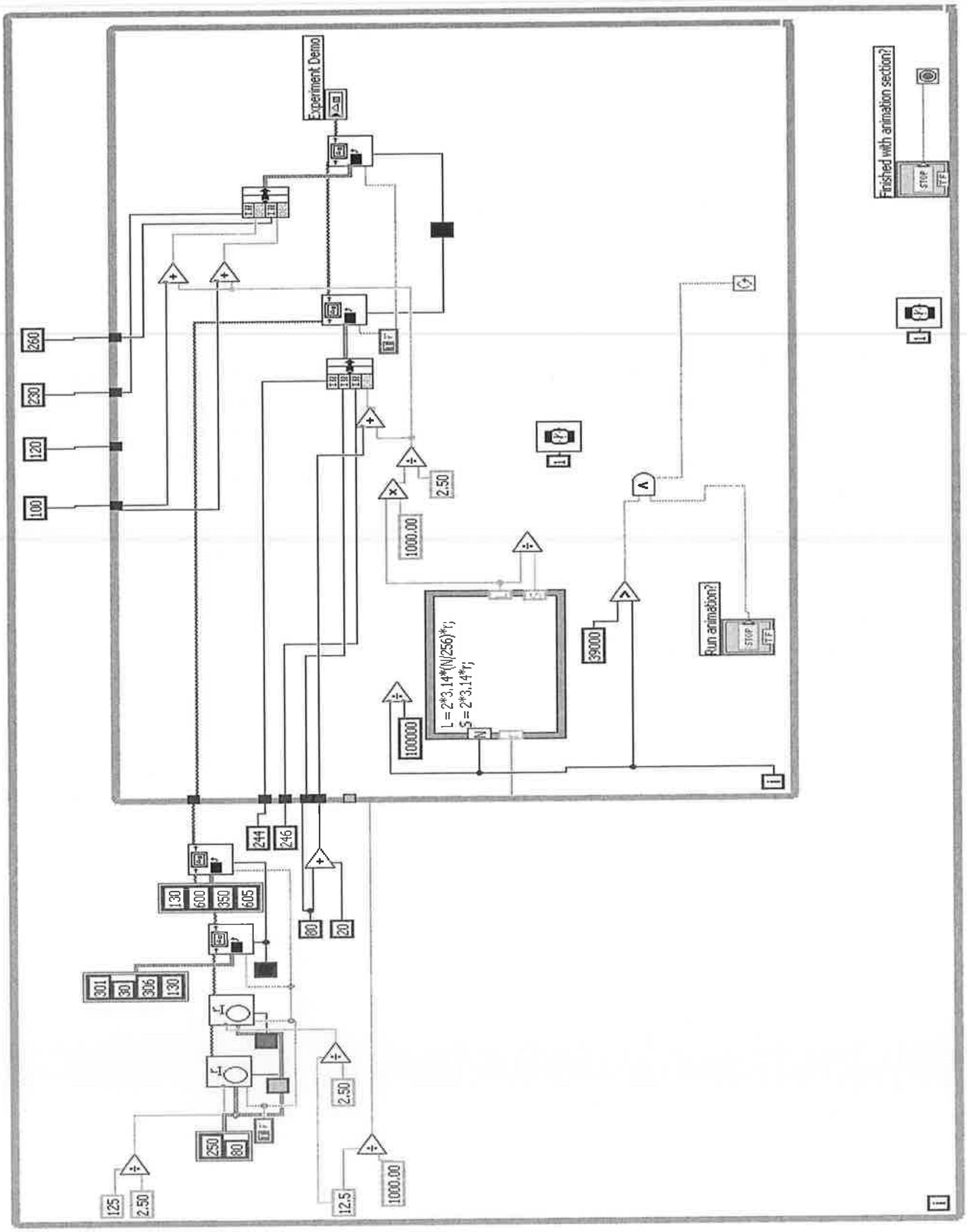


Figure A 2.2 Flywheel animation screen block diagram

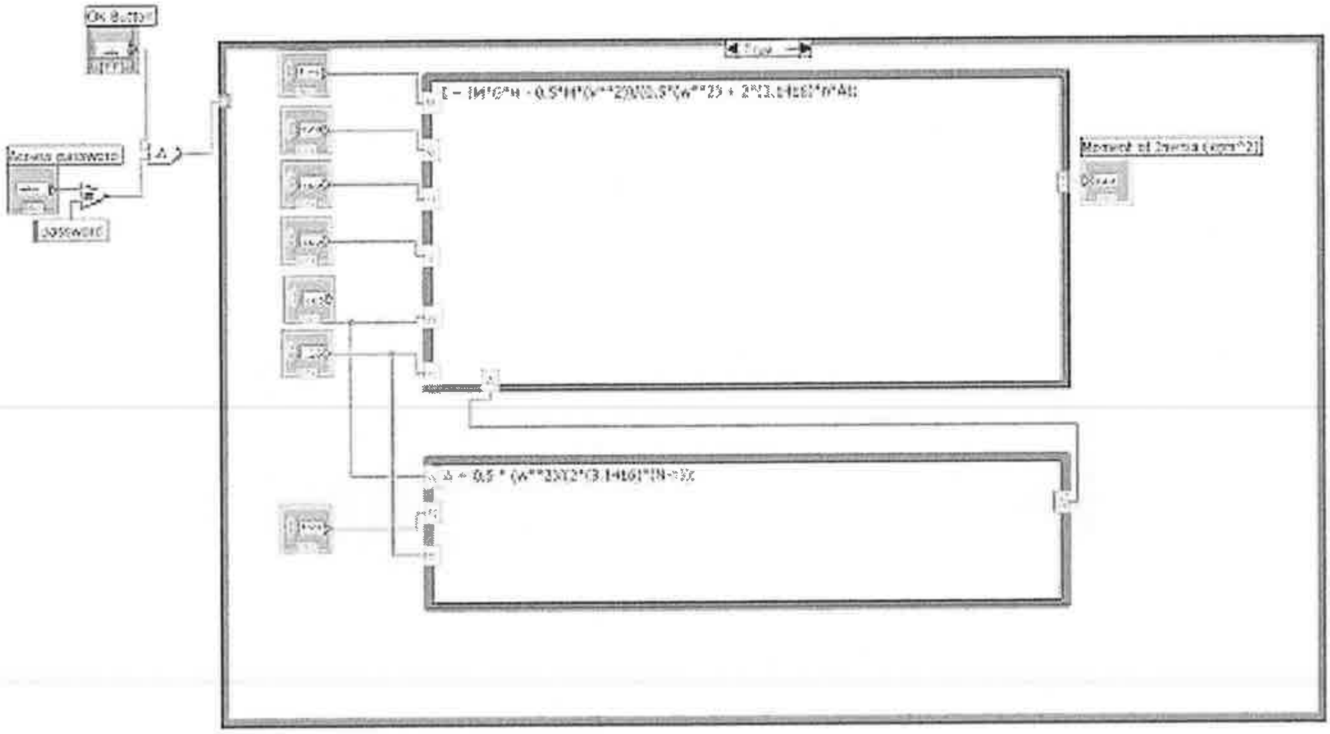


Figure A 2.3 Flywheel calculation screen block diagram

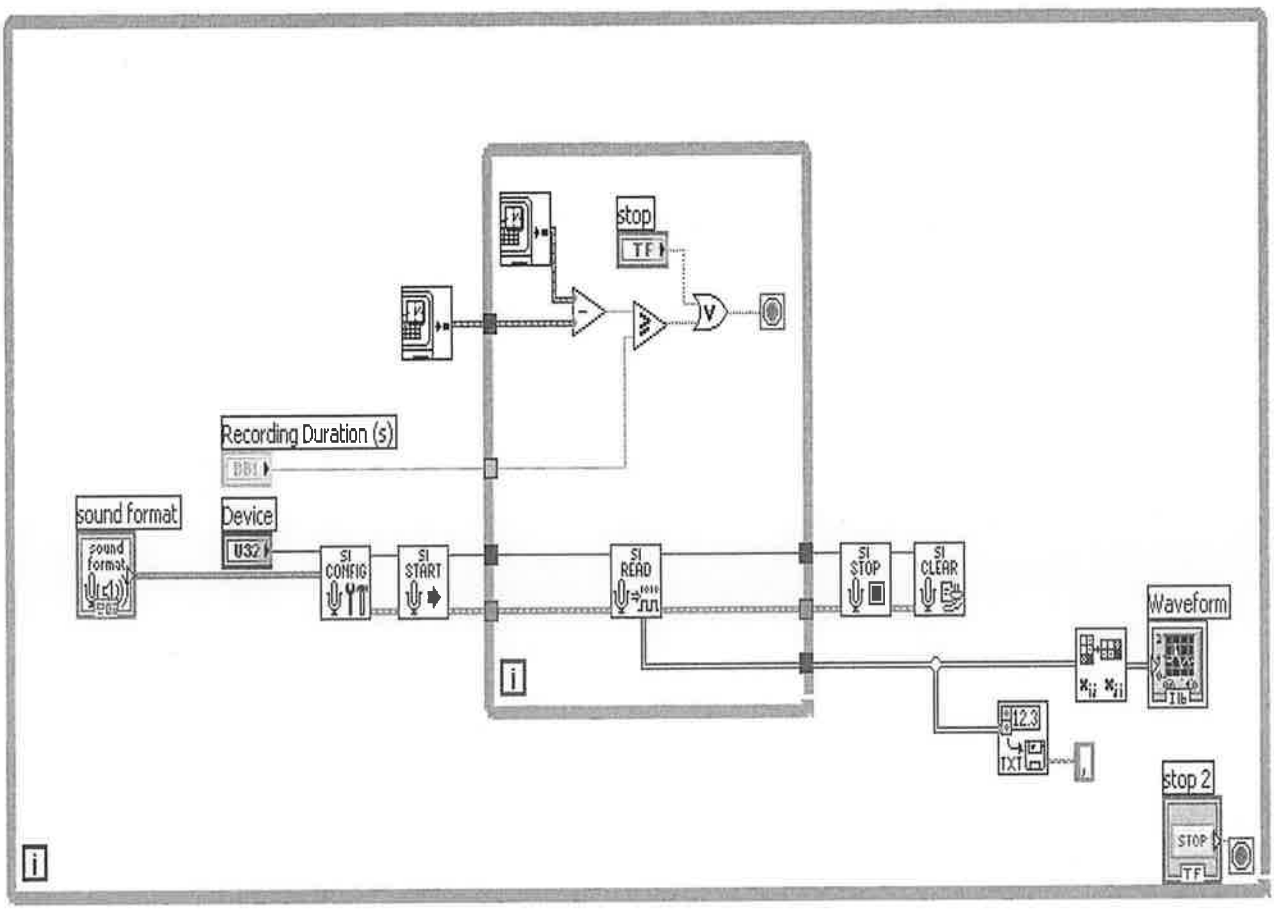


Figure A 2.4 Sound recording in use with the centrifugal force experiment

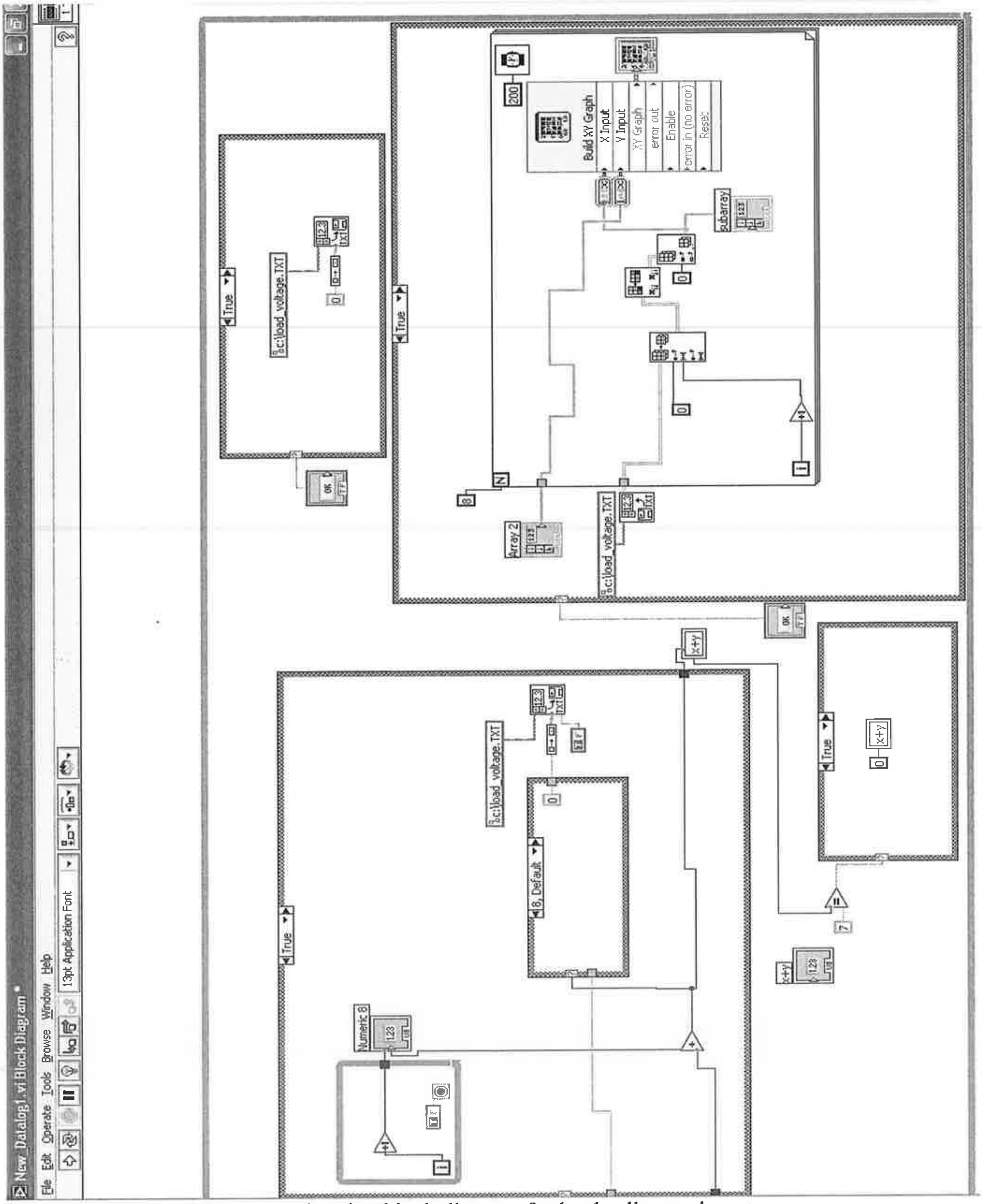


Figure A 2.5 Data logging block diagram for load cell experiment

Appendix B

B 1 Answer Sheets

B 1.1 Flywheel

B 1.2 Compound Pendulum

B 1.3 Centrifugal Force

B 2 Multiple Choice Questions

B 2.1 Flywheel

B 2.2 Compound Pendulum

B 2.3 Centrifugal Force

B 2.4 Load Cell

B 2.5 L.V.D.T.

B1.1 Flywheel Answer Sheet

Name:	Class:	Group:	Date:

EXPERIMENT M8 – ANSWER SHEET
DETERMINATION OF MOMENT OF INERTIA OF A FLYWHEEL

A1. List two everyday examples of a flywheel?

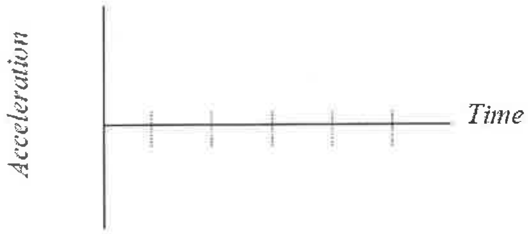
____

____

____

A2. By allowing the hanger attached to the flywheel to fall and observing

Plot the acceleration as a function of time, again for a few swings.



A3. Measure the distance **h** from the base of the hanger to the floor
h = __________ ± ______

A4. Explain how the energy "stored" within the system is transferred, relate this to the law of conservation of energy

____

____

____

____

Preliminary Questions discussed with demonstrator:
Signed: ______________________________ **Date:** ____________________

A5. Why is it important to have measured "h" from the base of the hanger and not from the axel of the flywheel?

A6. Let go of the hanger and allow it to fall towards the floor. Time the drop of the hanger to the instant of impact on the floor, and count the total number of turns made by the flywheel. Count the number of turns subsequently made by the flywheel. Repeat this several times under the same conditions (same height and no. of turns), and average the results.

Number.	of drop. s)	ber of turns re act.	l number rns.	ber of turns act.	ght used.

A7. Determine the average value for the number of turns before impact.
Number of turns = ____

A7a. Determine the average value for the number of turns after impact.
Number of turns = ____

A7b. Determine the average value for the drop time of the hanger.
Average time = ____

A8. Repeat parts A6 and A7 for a different weight.

Number.	of drop. s)	ber of turns re act.	l number rns.	ber of turns act.	ght used.

A9. Determine the average value for the number of turns before impact.
Number of turns = ____

A9a. Determine the average value for the number of turns after impact.
Number of turns = ____

A9b. Determine the average value for the drop time of the hanger.
Average time = ____

A10. Using equations [1] and [2] from your manual, calculate the values for the moment of inertia **I**, and the frictional torque, $\mathbf{T_f}$.

Moment of Inertia (I) = ________

Frictional Torque (T_f) = ________

A11. Calculate the geometrical value for the moment of inertia (from equations [3] and [4] in the manual) and compare the results with the experimental value.

You will do this by calculating the moment of inertia for each section of the flywheel and then adding them together.

A11a. Determine the mass of the axel and drum sections of the flywheel.

Mass of the narrow section 1 = _______ ± ____

Mass of the narrow section 2 = _______ ± ____

Mass of the drum section = _______ ± ____

A12. Determine the moment of inertia for each of the sections and thus determine the total moment of inertia for the system.

Moment of inertia for section 1 = _______ ± ____

Moment of inertia for section 2 = _______ ± ____

Moment of inertia for section 3 = _______ ± ____

Total moment of inertia = _______ ± ____

A13. Compare the actual value obtained to the theoretical value calculated.

Theory = ______

Actual = ______

A13a. If there is a difference in these values, explain why you think this is so?

____

____

____

____

____

____

A14. State what you deem to be the most important sources of error **other than human error** in order of importance. Include an estimate (in percents or absolute value) of its effect.

Source of error	Estimate (% or SI units)

A15. Discuss any remedies for the most important sources of error.

Name:	Class:	Group:	Date:

EXPERIMENT M9 – ANSWER SHEET
THE COMPOUND PENDULUM

A1. List three everyday examples of a simple pendulum?

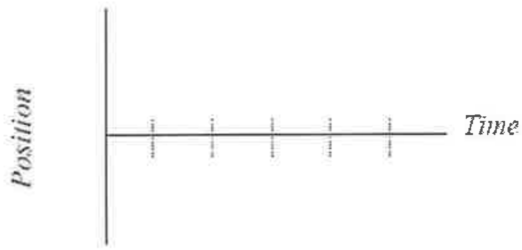
____

____

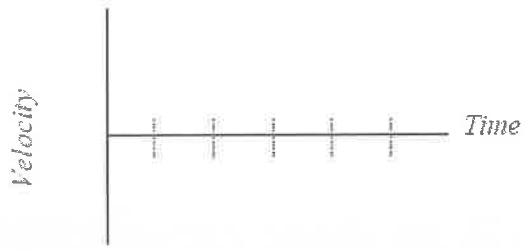
____

A2. By swinging the pendulum and observing what happens

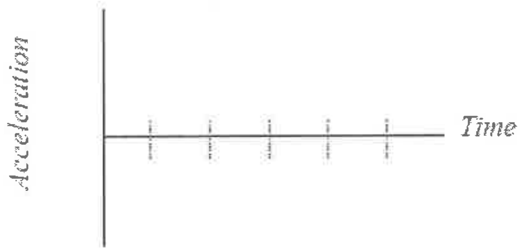
Plot the displacement as a function of time. Include a few swings.



Plot the velocity as a function of time. Include a few swings.



Plot the acceleration as a function of time, again for a few swings.



Preliminary Questions discussed with demonstrator:
Signed: ______________________________ **Date:** ______________

A3. Determine the position of the centre of gravity of the compound pendulum.
Centre of gravity = __________ ± _____

A4. Using the top hole of the pendulum, determine the period of oscillation for three angles of small amplitude (~ 5°, 10°, 15°). Enter the measured values in the table below.

)	lacement Angle rees)	l Time (s)	l Number of llations	Taken for one llation (s)

A5. Swing the simple pendulum through a small angle, and measure the periodic time of oscillation. Adjust the length of the string until this periodic time is the same as that found for the compound pendulum. Enter the measured values into the table below.

)	)	lacement e (degrees)	l Time (s)	l Number of llations	for one llation (s)

A6. Support the compound pendulum at each of the hole positions in turn, and for each location of the fulcrum, permit the pendulum to oscillate through a small angle, and note the corresponding periodic time of oscillation. Enter the measured values in the table below.

#	)	lacement e (degrees)	l Time (s)	l Number of llations	for one llation (s)
2					
3					
4					
5					
6					
7					

A7. On a separate sheet calculate the seven values of periodic time from the relationships given in your manual, and compare your measured values with this. Enter theses values into the table below.

#	leasured Value	alculated Value
2		
3		
4		
5		
6		
7		

A8. If there is a difference in these values, explain why you think this is so?

____

____

____

____

____

____

A9. State what you deem to be the most important sources of error **other than human error** in order of importance. Include an estimate (in percents or absolute value) of its effect.

Source of error	Estimate (% or SI units)

A10. Discuss any remedies for the most important sources of error.

B1.3 Centrifugal Force Answer Sheet

Name:	Class:	Group:	Date:

EXPERIMENT – ANSWER SHEET
CENTRIFUGAL FORCE EXPERIMENT

These sheets may be used as the results section of your report.

A1. List three everyday examples of where you could expect to see the effects of centrifugal force?

____

____

____

A2. Fill in the blank spaces in the following section with appropriate words:

Centripetal force and centrifugal force, action-reaction force pair associated with circular motion. According to Newton's first law of motion, a moving body travels along a straight path with constant speed (i.e., has constant velocity) unless it is acted on by an outside _______. For circular motion to occur there must be a constant force acting on a body, pushing it toward the _______ of the circular path. This force is the force. For a planet orbiting the sun, the force is gravitational; for an object twirled on a string, the force is mechanical; for an electron orbiting an atom, it is electrical. The magnitude F of the centripetal force is equal to the mass m of the body times its velocity squared v^2 divided by the radius r of its path: $F=mv^2/r$. According to Newton's third law of motion, for every action there is an equal and opposite _______. The centripetal force is balanced by a reaction force called the _________ ("center-fleeing") force. The two forces are equal in _________ and opposite in _________. The centrifugal force does not act on the body in motion; the only force acting on the body in motion is the centripetal force.

Preliminary Questions discussed with demonstrator:
Signed: ______________________________ **Date:** ________________

A3. Measure the distance from the axis to the pivots of the bell-cranks.
Distance (r_1) = __________ ± _____

A4. Ensure that the magnitude of the masses on the respective arms of the bell-cranks are the same.

A5. Replace the dome, and start the motor using the speed control unit. Slowly increase the speed until the bell-cranks are flung outward with an audible "click". Note the approximate speed at which this happens.

Speed (rev/min) = __________ (rev/min)

A6. Decrease the speed until the bell cranks returns to their original position. Once this is done you may increase the speed very slowly and repeat the reading.

If the two do not move at the same time, record the speed at which the first one moves, and note that both did not move together.

Speed (rev/min) = __________ (rev/min)

Did both bell cranks move at the same time ? ________

A7. By reducing the masses of the horizontal arm B (refer to diagram) by 25g at a time, obtain further results for each value of M_B, until you reach M_B = 50g.

You may use Table 1 provided in A10 to record your results.

A8. Repeat the series of tests for the other values of M_A, as suggested in Table 1.

A9. Repeat the series of tests for two other radial positions (keeping M_A constant at 50g), see Table 2.

A10.

M_B (g)	Gravity/ Centrifugal Force (N) $= M_B * g$	$M_A = 25g$		$M_A = 50g$		$M_A = 75g$	
		N (rev/min)	ω^2 (rad/sec)^2	N (rev/min)	ω^2 (rad/sec)^2	N (rev/min)	ω^2 (rad/sec)^2
175							
150							
125							
100							
75							
50							

Table 1 : Results for varying Speed and Mass Using Constant Radius

M_B (g)	Gravity/ Centrifugal Force (N) $= M_B * g$	r =		r =		r =	
		N (rev/min)	ω^2 (rad/sec)^2	N (rev/min)	ω^2 (rad/sec)^2	N (rev/min)	ω^2 (rad/sec)^2
175							
150							
125							
100							
75							
50							

Table 2 : Results for varying Speed and Radius Using a Constant Mass of 50g

A11. State what you deem to be the most important sources of error **other than human error** in order of importance. Include an estimate (in percents or absolute value) of its effect.

Source of error	Estimate (% or SI units)

A12. Discuss any remedies for the most important sources of error.

____

____

____

____

B2.1 Flywheel Multiple Choice Questions

A16. Complete the question set below, include all calculations and explanations on the sheet provided

A16a. What effect would wrapping the string around the drum of the flywheel as opposed to the axel to the:

	Increase	*Decrease*	*No Effect*
(a.) Velocity of the hanger	☐	☐	☐
(b.) Time of fall of hanger	☐	☐	☐
(c.) Moment of Inertia	☐	☐	☐

Explain briefly how you arrived at these answers:

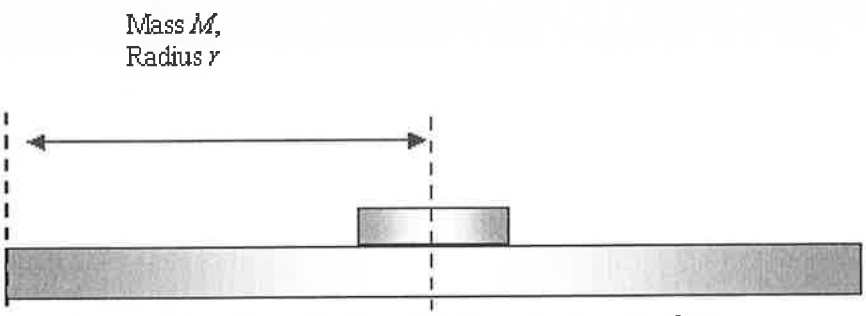
____

____

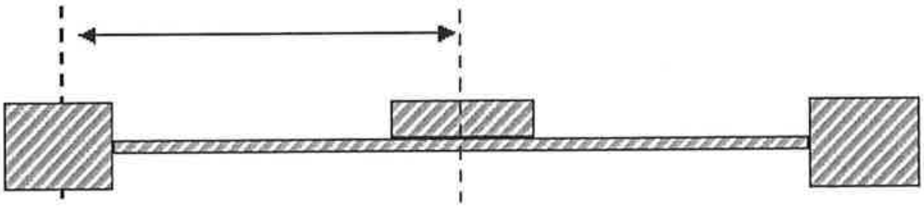
____

A16b. What is the best design for a flywheel? The obvious shape is a solid disk of steel. The diagram shows a couple of cross-sections. Both flywheels have the same mass and mean radius.

A solid disk flywheel: (a)



A flywheel that has a thin plate in the middle and most of its mass as a ring around the outside: (b)



(a) ☐ (b) ☐

Explain briefly how you arrived at these answers:

____

____

____

A16c. You are rewinding a video/audio tape and you record the speed at which it does so. Does the tape wind up fastest at (a) the start, (b) the end or (c) is constant throughout?

(a) Start ☐ (b) End ☐ (c) Constant ☐

Explain briefly how you arrived at these answers:

____

____

____

A16d. Consider a ballet dancer doing a spin called a pirouette. As she starts the spin the moment of inertia about the vertical axis is $3Kgm^2$. At the end of the spin her moment of inertia is reduced to just $1Kgm^2$. If she starts with an angular velocity of 1 rad/s, she finishes with an angular velocity of...

(a) 0.33 rad/s ☐ (b) 1 rad/s ☐ (c) 9 rad/s ☐ (d) 3 rad/s ☐

Explain briefly how you arrived at these answers:

____

____

____

B2.2 Compound Pendulum Multiple Choice Questions

A11. Complete the question set below, include all calculations and explanations on the sheet provided.

Question A11a.

What effect would running the experiment on the moon have on:

	Increase	*Decrease*	*No Affect*
(a.) Radius of gyration	☐	☐	☐
(b.) Periodic time of oscillation	☐	☐	☐
(c.) centre of gravity	☐	☐	☐

Explain briefly how you arrived at these answers:

____

____

____

Question A11b.

Given that $\theta'' = -g/R \sin\theta$, (where θ'' is the angular acceleration and θ is the angle), how does the mass, length or gravity affect the relationship between the angular acceleration and angle?

	Proportional	*Inversely Proportional*	*No Affect*
(a.) Mass	☐	☐	☐
(b.) Length	☐	☐	☐
(c.) gravity	☐	☐	☐

Explain briefly how you arrived at these answers

____

____

____

Question A11c.

A pendulum is mounted inside an elevator that accelerates upward with a constant acceleration. What affect does this have on the period of the oscillation?

	Increase	*Decrease*	*No Affect*
(a) Period	☐	☐	☐

Explain briefly how you arrived at these answers:

____

____

____

Question A11d.

What should you do to the length of the string of a simple pendulum in order to:

(a) Double the frequency...
(b) Double the period..
(c) Double the angular frequency ....

Explain briefly how you arrived at these answers:

____

____

____

B2.3 Centrifugal Force Multiple Choice Questions

A13. Complete the question set below, include all calculations and explanations on the sheet provided.

Question 13a.

A plastic cup filled with water is placed on a circular metal tray. The tray has 3 strings attached to its edge. Each of these is equidistant from each other and they all come together at a point above the tray and are wound together. The tray is swung in a circular fashion in a vertical plane, the water stays in the cup. Why?

____

____

____

When do you think the person swinging the tray has the hardest time keeping the water in the cup, at the beginning, the middle or the end of the swing?

____

Explain briefly why?

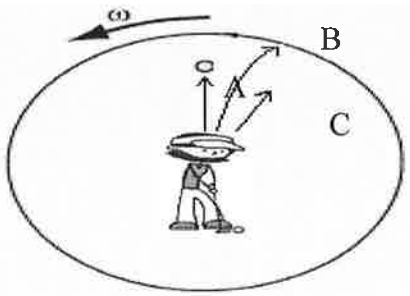
____

____

____

Question 2.

A golfer is standing at the middle of a rotating disc. He hits two identical shots at the hole on the disc in front of him, the first whilst the disc is stationary and the second whilst it is rotating clockwise. The first putt barely makes it to the hole and drops in. Which direction does the second shot take?



(a) ☐ (b) ☐ (c) ☐

Explain briefly why?

____

____

____

Question 3.

If you hang furry dice from the rear view mirror of your car and drive through a banked curve, how can you tell whether you are travelling less than, equal to, or greater than the speed used to calculate the banking angle?

(a) Less than

____

(b) Equal to

____

(c) Greater than

____

Explain briefly why?

____

____

____

____

Question 4.

An excited sir swings a rubber stopper in a horizontal circle on the end of a string in front of his class. He tells Phil sitting in the front row that he is going to release the string when it is directly in front of his face. Should Phil be worried?

(a) YES ☐ (b) NO ☐

Explain briefly why?

____

____

____

____

B2.5 Load Cell Multiple Choice Questions

Name............................
Student no.......................
Date..............................

Answer all questions on this sheet provided.

Load Cell Experiment.

Question 1.

A weighing system from trucks at a 24 hour border crossing is in operation. What effects, if any, would occur by having the strain gauges used in load cell exposed to direct sunlight

____

____

____

Explain briefly how you arrived at this answers:

____

____

____

Question 2.

Insert suitable words in the blank spaces to explain the operation of strain gauges:

The ideal strain gauge would change ___(a)___ only due to the deformations of the surface to which the sensor is attached. However, in real applications, ___(b)___, material properties, the adhesive that bonds the gauge to the surface, and the stability of the metal all affect the detected resistance. In bonding strain gage elements to a strained surface, it is important that the gauge experience the same ___(b)___ as the object.

(a)____________ (b) ____________ (c)____________

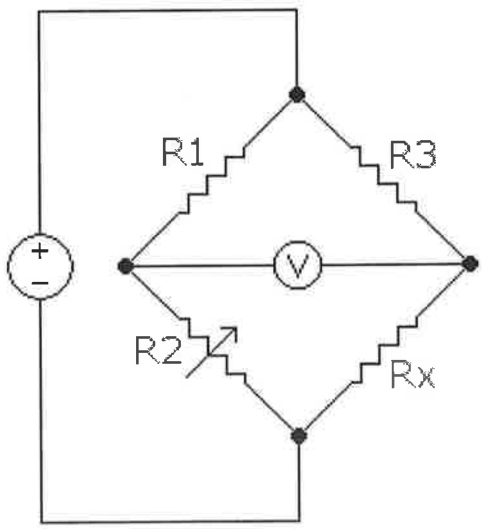
Explain briefly how you arrived at this answers:

____

____

____

Question 3.



In the diagram above, Rx is an unknown resistance to be measured; R1, R2 and R3 are resistors of known resistance and the resistance of R2 is variable. If the ratio of the two resistances in the known leg (R2/R1) is equal to the ratio of the two in the unknown leg (Rx/R3), explain what you would do in order to calculate the value of the unknown resistor Rx

____

____

____

____

Question 4.

Explain the term, “hysteresis”, and how it affects load cell operation?

____

____

____

____

____

B2.6 L.V.D.T. Multiple Choice Questions

Name.............................
Student no.......................
Date...............................

Answer all questions on this sheet provided.

L.V.D.T and Accelerometer Experiment.

Question 1.

(a) What would happen to the l.v.d.t. if its core was made out of copper as opposed to iron? Why?

____

____

____

(b) Why is it necessary to determine the phase of the output voltage of the l.v.d.t?

____

____

____

Question 2.

Insert suitable words in the blank spaces to explain the operation of l.v.d.t;

This sensor is a ____(a)____ with a single primary winding and two identical secondary windings, around a ____(b)____ core. The windings are powered by an a.c. voltage and with the core removed the output voltage is ____(c)____.

(a)____________ (b) ____________ (c)____________

Explain briefly how you arrived at this answers:

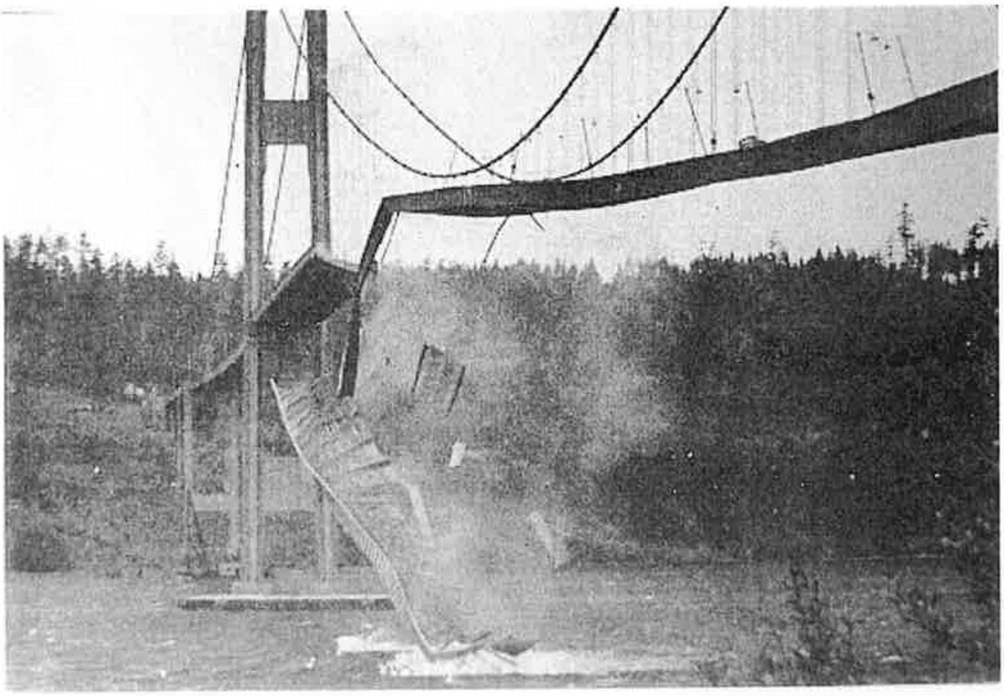
____

____

____

____

Question 3.



The Tacoma Narrows bridge famously collapsed in 1940. The reason given was that the wind happened to be travelling at a frequency equal to that of the *natural frequency* of the bridge. How could this cause the bridge to collapse?

____

____

____

____

Question 4.

Explain the term, "piezoelectric", and how can it be used in accelerometer operation?

Appendix C

C 1 Questionnaires

C 1.1 Original Questionnaire

C 1.2 Copies of selected opinion answers given

C 1.1 Original Questionnaire

Please answer the following questions in relation to the experiments. You should indicate your answer by circling the numbers below each question. "1" being extremely poor, "5" being adequate and "10" indicating that it could not be better.

Class ______________

1. Did you enjoy the lab?

1 2 3 4 5 6 7 8 9 10

2. Did you feel that you learned from this lab?

1 2 3 4 5 6 7 8 9 10

3. Was the procedure too long within the time given? (1 = too long, 10 = too short)

1 2 3 4 5 6 7 8 9 10

4. How well did the lab relate to material covered in lectures?

1 2 3 4 5 6 7 8 9 10

5. Was the experimental procedure clear and easy to understand?

1 2 3 4 5 6 7 8 9 10

6. How boring was the lab? (1 = exciting, 10 = extremely boring)

1 2 3 4 5 6 7 8 9 10

7. Was the theory to be learned from the lab clear from the lab?

1 2 3 4 5 6 7 8 9 10

8. Was the demonstration at the start of the lab adequate?

1 2 3 4 5 6 7 8 9 10

9. Was the demonstration adequate throughout the lab?

1 2 3 4 5 6 7 8 9 10

10. In your opinion was the lab beneficial to you in relation to your course?

1 2 3 4 5 6 7 8 9 10

11. Where any of the lab experiments you did in this semester instrumented on computer?

Yes No

12a. If yes, do you think it benefited you to do so

Yes No

12b. If no, do you think it would have benefited you

Yes No

13. Would you prefer to use the experiments as they are now (A) or would you like to see them use more computer based technology including animations, data-logging and virtual experimentation (B) ?

(A) (B)

14. What problems do you have with the labs in their current state?

____

____

____

15. How would you like to improve laboratory experiments?

____

16. Do you think that using a computer to learn and aid in the laboratory is better having to rely of the demonstrator for help?

Yes No

17. Do you prefer to write up your lab report in labs or at home?

Lab Home

18. Would you prefer to have access to an online version of the experiment to reference once you have completed the lab?

Yes No Thank you

C 1.2.1

11. Were any of the lab experiments you did in this semester interfaced with a computer?

Yes No

12a. If yes, do you think the computer interface was a beneficial learning aid?

Yes No

12b. If no, do you think it could have benefited you?

Yes No

13. Would you prefer to use the experiments as they are now (A) or would you like to see them use more computer based, including animations and data-logging (B) ?

(A) (B)

14. Are there any problems you can se with the labs in their current state?

BORING !! BUT LABS ARE SUPPOSED TO BE!

15. Is there anything you would like to see changed to improve the delivery of laboratory experiments?

MORE COMPUTER BASED, THEY ARE EASIER TO UNDERSTAND, AND NOT AS LONG

16. Do you think that using a computer to learn and aid in the laboratory is better than having to rely of the demonstrator for help?

Yes No

17. Do you prefer to write up your lab report in labs or at home?

Lab Home

18. Would you like to have access to an online version of the experiment to reference once you have completed the lab?

Yes No

Figure C.1 Questionnaire sheet one from students who attempted instrumented experiment

C 1.2.2

11. Were any of the lab experiments you did in this semester interfaced with a computer?

Yes No

12a. If yes, do you think the computer interface was a beneficial learning aid?

Yes No

12b. If no, do you think it could have benefited you?

Yes No

13. Would you prefer to use the experiments as they are now (A) or would you like to see them use more computer based, including animations and data-logging (B) ?

(A) (B)

14. Are there any problems you can se with the labs in their current state?

Most of the labs in no way relate to the lectures. So for the most part you are doing experiments on things you haven't seen before.

15. Is there anything you would like to see changed to improve the delivery of laboratory experiments?

Have them more computer based

16. Do you think that using a computer to learn and aid in the laboratory is better than having to rely of the demonstrator for help?

Yes No

17. Do you prefer to write up your lab report in labs or at home?

Lab Home

18. Would you like to have access to an online version of the experiment to reference once you have completed the lab?

Yes No

Figure C.2 Questionnaire sheet one from students who attempted instrumented experiment

C 1.2.3

11. Were any of the lab experiments you did in this semester interfaced with a computer?

Yes No

12a. If yes, do you think the computer interface was a beneficial learning aid?

Yes No

12b. If no, do you think it could have benefited you?

Yes No

13. Would you prefer to use the experiments as they are now (A) or would you like to see them use more computer based, including animations and data-logging (B) ?

(A) (B)

14. Are there any problems you can se with the labs in their current state?

Some equipment is [illegible] inaccurate or [illegible] used eg [illegible] in PH

15. Is there anything you would like to see changed to improve the delivery of laboratory experiments?

Some examples of calculations

16. Do you think that using a computer to learn and aid in the laboratory is better than having to rely of the demonstrator for help?

Yes No

17. Do you prefer to write up your lab report in labs or at home?

Lab Home

18. Would you like to have access to an online version of the experiment to reference once you have completed the lab?

Yes No

Figure C.3 Questionnaire sheet one from students who attempted instrumented experiment

C 1.2.4

11. Were any of the lab experiments you did in this semester interfaced with a computer?

Yes No

12a. If yes, do you think the computer interface was a beneficial learning aid?

Yes No

12b. If no, do you think it could have benefited you? ?

Yes No

13. Would you prefer to use the experiments as they are now (A) or would you like to see them use more computer based, including animations and data-logging (B) ?

(A) (B)

14. Are there any problems you can se with the labs in their current state?

Some are too long with too many Questions.

15. Is there anything you would like to see changed to improve the delivery of laboratory experiments?

less questions.

16. Do you think that using a computer to learn and aid in the laboratory is better than having to rely of the demonstrator for help?

Yes No

17. Do you prefer to write up your lab report in labs or at home?

Lab Home

18. Would you like to have access to an online version of the experiment to reference once you have completed the lab?

Yes No

Figure C.4 Questionnaire sheet one from students who attempted instrumented experiment

Appendix D

D 1 Specification sheets

D 1.1 National Instruments 6009 USB DAQ box

D 1.2 National instruments SCB – 68 DAQ box

D 1.3 Rotational senor for flywheel experiment

D 1.4 Optical sensor for compound pendulum experiment

D 1.5 Accelerometer for L.V.D.T experiment

D 1.6 Microphone specifications for centrifugal force experiment

D 1.1 NI USB 6009

Low-Cost Multifunction DAQ for USB

NI USB-6008, NI USB-6009

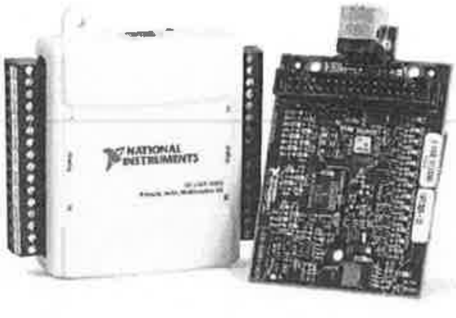
- Small and portable
- 12 or 14-bit input resolution, at up to 48 kS/s
- Built-in, removable connectors for easier and more cost-effective connectivity
- 2 true DAC analog outputs for accurate output signals
- 12 digital I/O lines (TTL/LVTTL/CMOS)
- 32-bit event counter
- Student kits available
- OEM versions available

Operating Systems
- Windows 2000/XP
- Mac OS X[1]
- Linux®[1]
- Pocket PC
- Win CE

Recommended Software
- LabVIEW
- LabWindows/CVI

Measurement Services Software (included)
- NI-DAQmx
- Ready-to-run data logger

[1]Mac OS X and Linux users need to download NI-DAQmx Base.



Product	Bus	Analog Inputs[1]	Input Resolution (bits)	Max Sampling Rate (kS/s)	Input Range (V)	Analog Outputs	Output Resolution (bits)	Output Rate (Hz)	Output Range (V)	Digital I/O Lines	32-Bit Counter	Trigger
USB-6009	USB	8 SE/4 DI	14	48	±1 to ±20	2	12	150	0 to 5	12	1	Digital
USB-6008	USB	8 SE/4 DI	12	10	±1 to ±20	2	12	150	0 to 5	12	1	Digital

[1]SE = single ended, DI = differential

Hardware Description

The National Instruments USB-6008 and USB-6009 multifunction data acquisition (DAQ) modules provide reliable data acquisition at a low price. With plug-and-play USB connectivity, these modules are simple enough for quick measurements but versatile enough for more complex measurement applications.

Software Description

The NI USB-6008 and USB-6009 use NI-DAQmx high-performance, multithreaded driver software for interactive configuration and data acquisition on Windows OSs. All NI data acquisition devices shipped with NI-DAQmx also include VI Logger Lite, a configuration-based data-logging software package.

Mac OS X and Linux users can download NI-DAQmx Base, a multiplatform driver with a limited NI-DAQmx programming interface. You can use NI-DAQmx Base to develop customized data acquisition applications with National Instruments LabVIEW or C-based development environments. NI-DAQmx Base includes a ready-to-run data logger application that acquires and logs up to eight channels of analog data.

PDA users can download NI-DAQmx Base for Pocket PC and Win CE to develop customized handheld data acquisition applications.

Recommended Accessories

The USB-6008 and USB-6009 have removable screw terminals for easy signal connectivity. For extra flexibility when handling multiple wiring configurations, NI offers the USB-6008/09 Accessory Kit, which includes two extra sets of screw terminals, extra labels, and a screwdriver.

In addition, the USB-6008/09 Prototyping Accessory provides space for adding more circuitry to the inputs of the USB-6008 or USB-6009.

Common Applications

The USB-6008 and USB-6009 are ideal for a number of applications where economy, small size, and simplicity are essential, such as:
- Data logging – Log environmental or voltage data quickly and easily.
- Academic lab use – The low price facilitates student ownership of DAQ hardware for completely interactive lab-based courses. (Academic pricing available. Visit **ni.com/academic** for details.)
- Embedded OEM applications.

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Figure D.1 Specification sheet one for the USB 6009

Specifications

Typical at 25 °C unless otherwise noted.

Analog Input

Absolute accuracy, single-ended

Range	Typical at 25 °C (mV)	Maximum (0 to 55 °C) (mV)
±10	14.7	138

Absolute accuracy at full scale, differential[1]

Range	Typical at 25 °C (mV)	Maximum (0 to 55 °C) (mV)
±20	14.7	138
±10	7.73	84.8
±5	4.28	58.4
±4	3.59	53.1
±2.5	2.56	45.1
±2	2.21	42.5
±1.25	1.70	38.9
±1	1.53	37.5

Number of channels .... 8 single-ended/4 differential
Type of ADC .... Successive approximation

ADC resolution (bits)

Module	Differential	Single-Ended
USB-6008	12	11
USB-6009	14	13

Maximum sampling rate (system dependent)

Module	Maximum Sampling Rate (kS/s)
USB-6008	10
USB-6009	48

Input range, single-ended .... ±10 V
Input range, differential .... ±20, ±10, ±5, ±4, ±2.5, ±2, ±1.25, ±1 V
Maximum working voltage .... ±10 V
Overvoltage protection .... ±35 V
FIFO buffer size .... 512 B
Timing resolution .... 41.67 ns (24 MHz timebase)
Timing accuracy .... 100 ppm of actual sample rate
Input impedance .... 144 k
Trigger source .... Software or external digital trigger
System noise .... 0.3 LSB_{rms} (±10 V range)

Analog Output

Absolute accuracy (no load) .... 7 mV typical, 36.4 mV maximum at full scale
Number of channels 2
Type of DAC .... Successive approximation
DAC resolution .... 12 bits
Maximum update rate .... 150 Hz, software-timed
Output range .... 0 to +5 V
Output impedance .... 50 Ω
Output current drive .... 5 mA
Power-on state .... 0 V
Slew rate .... 1 V/µs
Short-circuit current .... 50 mA

Digital I/O

Number of channels .... 12 total
8 (P0.<0..7>)
4 (P1.<0..3>)
Direction control .... Each channel individually programmable as input or output
Output driver type
USB-6008 .... Open-drain
USB-6009 .... Each channel individually programmable as push-pull or open-drain
Compatibility .... CMOS, TTL, LVTTL
Internal pull-up resistor .... 4.7 kΩ to +5 V
Power-on state .... Input (high impedance)
Absolute maximum voltage range .... -0.5 to +5.8 V

Digital logic levels

Level	Min	Max	Units
Input low voltage	-0.3	0.8	V
Input high voltage	2.0	5.8	V
Input leakage current	–	50	µA
Output low voltage (I = 8.5 mA)	–	0.8	V
Output high voltage (push-pull, I = -8.5 mA)	2.0	3.5	V
Output high voltage (open-drain, I = -0.6 mA, nominal)	2.0	5.0	V
Output high voltage (open-drain, I = -8.5 mA, with external pull-up resistor)	2.0	–	V

Counter

Number of counters 1
Resolution .... 32 bits
Counter measurements .... Edge counting (falling edge)
Pull-up resistor .... 4.7 kΩ to 5 V
Maximum input frequency .... 5 MHz
Minimum high pulse width .... 100 ns
Minimum low pulse width .... 100 ns
Input high voltage .... 2.0 V
Input low voltage .... 0.8 V

Power available at I/O connector

+5 V output (200 mA maximum) .... +5 V typical
+4.85 V minimum
+2.5 V output (1 mA maximum) .... +2.5 V typical
+2.5 V output accuracy .... 0.25% max
Voltage reference temperature drift .... 50 ppm/°C max

[1]Input voltages may not exceed the working voltage range.

Figure D.2 Specification sheet two for the USB 6009

Physical Characteristics

If you need to clean the module, wipe it with a dry towel.

Dimensions (without connectors)	6.35 by 8.51 by 2.31 cm (2.50 by 3.35 by 0.91 in.)
Dimensions (with connectors)	8.18 by 8.51 by 2.31 cm (3.22 by 3.35 by 0.91 in.)
Weight (without connectors)	59 g (2.1 oz)
Weight (with connectors)	84 g (3 oz)
I/O connectors	USB series B receptacle (2) 16-position (screw-terminal) plug headers
Screw-terminal wiring	16 to 28 AWG
Screw-terminal torque	0.22 to 0.25 N•m (2.0 to 2.2 lb•in.)

Power Requirement

USB (4.10 to 5.25 VDC)	80 mA typical 500 mA maximum
USB suspend	300 µA typical 500 µA maximum

Environmental

The USB-6008 and USB-6009 are intended for indoor use only.

Operating environment	
Ambient temperature range	0 to 55 °C (tested in accordance with IEC-60068-2-1 and IEC-60068-2-2)
Relative humidity range	10 to 90%, noncondensing (tested in accordance with IEC-60068-2-56)
Storage environment	
Ambient temperature range	-40 to 85 °C (tested in accordance with IEC-60068-2-1 and IEC-60068-2-2)
Relative humidity range	5 to 90%, noncondensing (tested in accordance with IEC-60068-2-56)
Maximum altitude	2,000 m (at 25 °C ambient temperature)
Pollution degree	2

Safety and Compliance

Safety

This product is designed to meet the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CAN/CSA-C22.2 No. 61010-1

Note: For UL and other safety certifications, refer to the product label or visit **ni.com/certification**, search by model number or product line, and click the appropriate link in the Certification column.

Electromagnetic Compatibility

This product is designed to meet the requirements of the following standards of EMC for electrical equipment for measurement, control, and laboratory use:

- EN 61326 EMC requirements; Minimum Immunity
- EN 55011 Emissions; Group 1, Class A
- CE, C-Tick, ICES, and FCC Part 15 Emissions; Class A

Note: For EMC compliance, operate this device according to product documentation.

CE Compliance

This product meets the essential requirements of applicable European Directives, as amended for CE marking, as follows:

- 73/23/EEC; Low-Voltage Directive (safety)
- 89/336/EEC; Electromagnetic Compatibility Directive (EMC)

Note: Refer to the Declaration of Conformity (DoC) for this product for any additional regulatory compliance information. To obtain the DoC for this product, visit **ni.com/certification**, search by model number or product line, and click the appropriate link in the Certification column.

Waste Electrical and Electronic Equipment (WEEE)

EU Customers: At the end of their life cycle, all products must be sent to a WEEE recycling center. For more information about WEEE recycling centers and National Instruments WEEE initiatives, visit **ni.com/environment/weee.htm**.

Figure D.3 Specification sheet three for the USB 6009

D 1.2 NI SCB-68 DAQ

A

Specifications

This appendix lists the SCB-68 specifications. These ratings are typical at 25 °C unless otherwise stated.

Analog Input

Number of channels

68-pin DAQ devices .... Eight differential, 16 single-ended

100-pin DAQ devices .... 32 differential, 64 single-ended

Temperature sensor

Accuracy .... ±1.0 °C over a 0 to 110 °C range

Output .... 10 mV/°C

Power Requirement

Power consumption (at +5 VDC, ±5%)

Typical .... 1 mA with no signal conditioning installed

Maximum .... 800 mA from host computer

Note The power specifications pertain to the power supply of the host computer when using internal power or to the external supply connected at the +5 V screw terminal when using external power. The maximum power consumption of the SCB-68 is a function of the signal conditioning components installed and any circuits constructed on the general-purpose breadboard area. If the SCB-68 is powered from the host computer, the maximum +5 V current draw, which is limited by the fuse, is 800 mA.

Fuse

Manufacturer .... Littelfuse

Part number 235 800

Ampere rating .... 0.800 A

© National Instruments Corporation *A-1* *SCB-68 Shielded Connector Block User Manual*

Figure D.4 Specification sheet one for the SCB-69

Voltage rating ....250 V

Nominal resistance ....0.195 Ω

Physical

Box dimensions (including box feet)......19.5 by 15.2 by 4.5 cm
(7.7 by 6.0 by 1.8 in.)

I/O connectors...One 68-pin male SCSI connector

Screw terminals 68

Wire gauge..≤26 AWG

Resistor sockets ....0.032 to 0.038 in. (in diameter)

Maximum Working Voltage

Maximum working voltage refers to the signal voltage plus the common-mode voltage.

Channel-to-earth ....42 V_{rms}, Installation Category II

Channel-to-channel.................................42 V_{rms}, Installation Category II

Environmental

Operating temperature ....0 to 70 °C

Storage temperature ....–20 to 70 °C

Humidity ....5 to 90% RH, noncondensing

Maximum altitude...................................2000 meters

Pollution Degree (indoor use only) II

Figure D.5 Specification sheet two for the SCB-69

Safety

The SCB-68 meets the requirements of the following standards for safety and electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 3111-1
- CAN/CSA C22.2 No. 1010.1

Note For UL and other safety certifications, refer to the product label or to `ni.com`.

Electromagnetic Compatibility

Emissions .... EN 55011 Class A at 10 m
FCC Part 15A above 1 GHz

Immunity .... EN 61326-1:1997 + A1:1998, Table 1

EMC/EMI .... CE, C-Tick, and FCC Part 15 (Class A) Compliant

Note For EMC compliance, you *must* operate this device with shielded cabling.

CE Compliance

This product meets the essential requirements of applicable European Directives, as amended for CE Marking, as follows:

Low-Voltage Directive (safety) 73/23/EEC

Electromagnetic Compatibility
Directive (EMC) 89/336/EEC

Note Refer to the Declaration of Conformity (DoC) for this product for any additional regulatory compliance information. To obtain the DoC for this product, click **Declaration of Conformity** at `ni.com/hardref.nsf/`. This Web site lists the DoCs by product family. Select the appropriate product family, followed by your product, and a link to the DoC appears in Adobe Acrobat format. Click the Acrobat icon to download or read the DoC.

Figure D.6 Specification sheet three for the SCB-69

D 1.3 Rotational sensor

Panel Mount Optical Encoders

Technical Data

HEDS-5700 Series

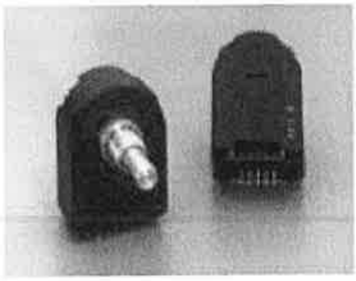
Features

- Two Channel Quadrature Output with Optional Index Pulse
- Available with or without Static Drag for Manual or Mechanized Operation
- High Resolution – Up to 512 CPR
- Long Rotational Life, >1 Million Revolutions
- -20 to 85°C Operating Temperature Range
- TTL Quadrature Output
- Single 5 V Supply
- Available with Color Coded Leads

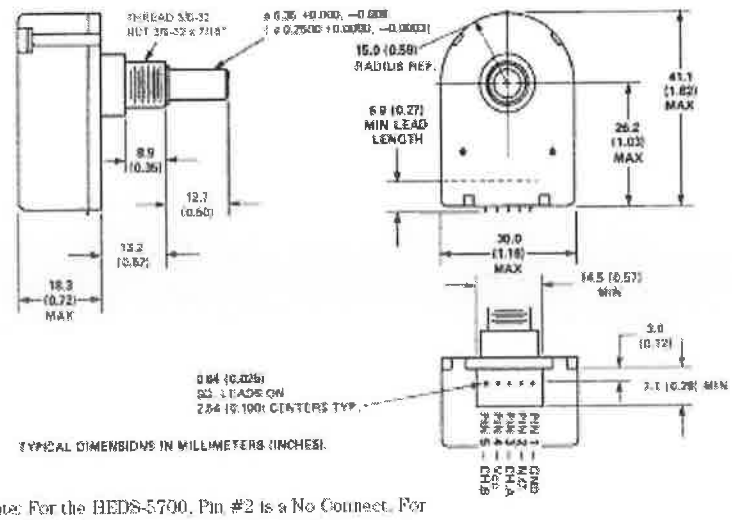
Description

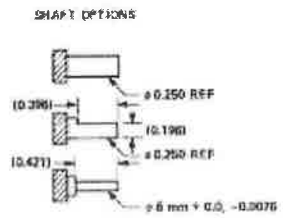
The HEDS-5700 series is a family of low cost, high performance, optical incremental encoders with mounted shafts and bushings. The HEDS-5700 is available with tactile feedback for hand operated panel mount applications, or with a free spinning shaft for applications requiring a pre-assembled encoder for position sensing.

The encoder contains a collimated LED light source and special detector circuit which allows for high resolution, excellent encoding performance, long rotational life, and increased reliability. The unit outputs two digital waveforms which are 90 degrees out of phase to provide position and direction information. The HEDS-5740 Series provides a third Index Channel.



Package Dimensions





OPTIONAL WIRING COLOR CODE TABLE	
COLOR	OUTPUT
WHITE	A
BROWN	B
RED	Vcc
BLACK	GND
BLUE (THREE CHANNEL)	I

*Note: For the HEDS-5700, Pin #2 is a No Connect. For the HEDS-5740, Pin #2 is Channel I, the index output.

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5965-5871E

Figure D.7 Specification sheet one for the HP Rotational sensor

The HEDS-5700 is quickly and easily mounted to a front panel using the threaded bushing, or it can be directly coupled to a motor shaft (or gear train) for position sensing applications.

Applications

The HEDS-5700 with the static drag option is best suited for applications requiring digital information from a manually operated knob. Typical front panel applications include instruments, CAD/CAM systems, and audio/video control boards.

The HEDS-5700 without static drag (free spinning) is best suited for low speed, mechanized operations. Typical applications are copiers, X-Y tables, and assembly line equipment.

Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Units	Notes
Storage Temperature	T_s	-40	+85	°C	
Operating Temperature	T_a	-20	+85	°C	
Vibration			20	g	20 Hz - 2 kHz
Supply Voltage	V_{CC}	-0.5	7	V	
Output Voltage	V_O	-0.5	V_{CC}	V	
Output Current per Channel	I_O	-1	5	mA	
Shaft Load – Axial			1	lb	
– Radial			1	lb	

Recommended Operating Conditions

Parameter	Symbol	Min.	Max.	Units	Notes
Temperature	T	-20	+85	°C	Noncondensing Atmosphere
Supply Voltage	V_{CC}	4.5	5.5	V	Ripple <100 mV_{p-p}
Rotational Speed – Drag			300	RPM	
– Free Spinning			2000	RPM	

Electrical Characteristics Over Recommended Operating Range, Typical at 25°C

Parameter	Symbol	Min.	Typ.	Max.	Units	Notes
Supply Current	I_{CC}		17	40	mA	Two Channel
			57	85		Three Channel
High Level Output Voltage	V_{OH}	2.4			V	I_{OH} = -40 µA Max.
Low Level Output Voltage	V_{OL}			0.4	V	I_{OL} = 3.2 mA

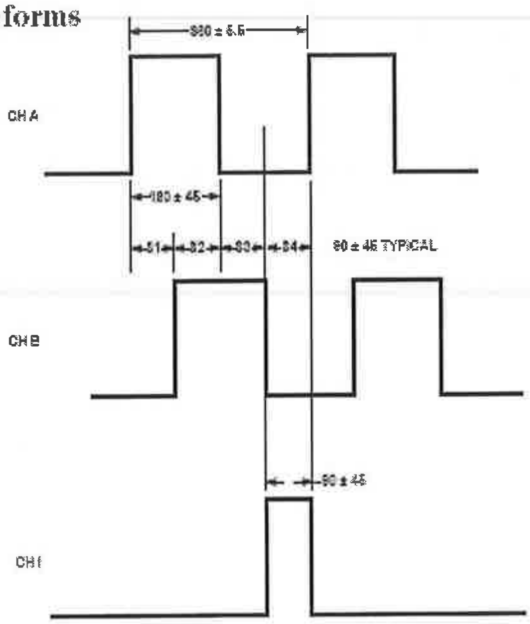
Note: If more source current is required, use a 3.2 K pullup resistor on each output.

Figure D.8 Specification sheet two for the HP Rotational sensor

Mechanical Characteristics

Parameter		Min.	Typ.	Max.	Units	Notes
Starting Torque	– Static Drag		0.47		oz in	
	– Free Spinning			0.14	oz in	
Dynamic Drag	– Static Drag		1.1		oz in	100 RPM
	– Free Spinning		0.70		oz in	2000 RPM
Rotational Life	– Static Drag	1 x 10^6			Revolutions	1 lb Load
	– Free Spinning	12 x 10^6			Revolutions	4 oz Radial Load
Mounting Torque of Nut				13	lb in	

Output Waveforms



NOTE:
ALL VALUES ARE IN ELECTRICAL DEGREES, WHERE 360° e = 1 CYCLE OF RESOLUTION.
ERRORS ARE WORST CASE OVER ONE REVOLUTION.
CH B LEADS CH A FOR COUNTERCLOCKWISE ROTATION.
CH A LEADS CH B FOR CLOCKWISE ROTATION.

Ordering Information

HEDS-57□□-□□□

Outputs
0 - 2 Channel
4 - 3 Channel

Mechanical Configuration
0 - Pins
1 - 6" Coded Leads

Resolutions (Cycles Per Revolution)

HEDS-570X 2 Channel
K - 96 CPR
C - 100 CPR
D - 192 CPR
E - 200 CPR
F - 256 CPR
G - 360 CPR
H - 400 CPR
A - 500 CPR
I - 512 CPR

HEDS-574X Three Channel*
F - 256 CPR
G - 360 CPR
A - 500 CPR
I - 512 CPR

Drag Option
0 - Free Spining
1 - Static Drag

Shaft Configuration
0 - 1/4" dia. with no flat
1 - 6 mm dia. with no flat
2 - 1/4" dia. with flat

*Please contact factory for other resolutions.

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Figure D.9 Specification sheet three for the HP Rotational sensor

D 1.4 Optical sensor for compound pendulum experiment

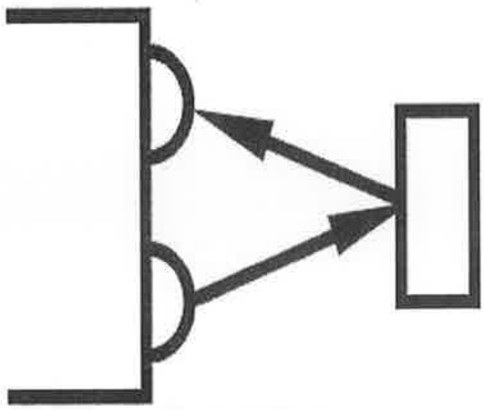
Min. pre-wired detector,PNP o/p 400mm

Attributes	
Search by product type	Photoelectric
Supply Voltage	10 to 30V(dc)
Depth	24mm
Height	26.4mm
Housing-Body Material	PBT
IP Rating	IP67
LED Status Display	Yes
Light Source	LED Yellow; Red
Mounting	Mounting Bracket
Output Type	PNP
Overload Protection	Yes
Range	400mm
Response Time	1 ms (Delay)
Selectable Light-Dark Output	Yes
Sensing Face Material	PMMA (Lens)
Width	12mm

Over view

Direct Detect - 400mm

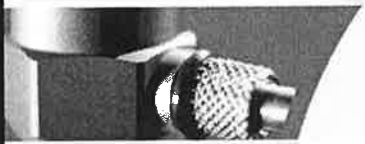
- IR 950nm
- Stability control indicator
- Readiness time delay 30ms
- Rise time delay 1ms
- Dimensions 24 x 26.4 x 12mm



View larger image

Figure D.10 Specification sheet for Pepperl and Fuchs optical sensor

D 1.5 Accelerometer for L.V.D.T experiment

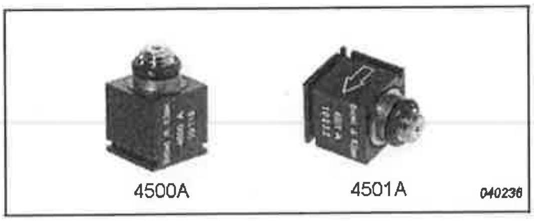


PRODUCT DATA

Piezoelectric Accelerometer
Cubic Charge Accelerometers — Types 4500 A and 4501 A

Types 4500 A and 4501 A are cubic piezoelectric ThetaShear® accelerometers. These cubic accelerometers have low sensitivity to extraneous environmental effects, which is achieved through the ThetaShear design. The accelerometers feature a 10–32 UNF connector. On Type 4500 A, it is positioned on the top surface, which is perpendicular to its main axis. On Type 4501 A, it is positioned on the side surface, which is parallel to its main axis.

The piezoelectric element used is the PZ 23 lead zirconate titanate element. The housing is aluminium.



USES AND FEATURES

USES
- General purpose multi-axis vibration and shock measurements on low-mass structures and in confined spaces
- Excellent for applications where a large number of accelerometers are required

FEATURES
- Low weight
- Low sensitivity to environmental factors
- Electrically insulated for ground-loop protection
- High resonance frequency

Characteristics

This piezoelectric accelerometer may be treated as a charge source. Its sensitivity is expressed in terms of charge per unit acceleration (pC/g).

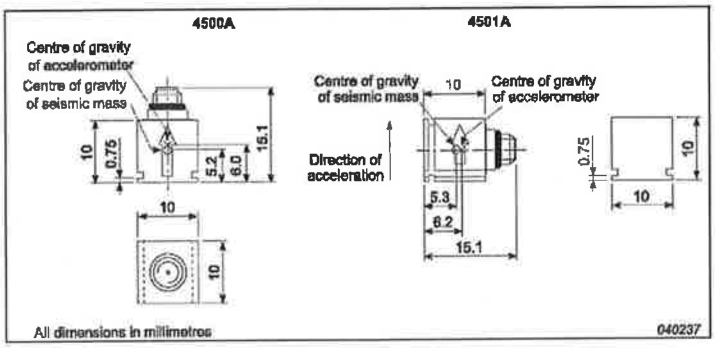
The ThetaShear design involves a slotted cylindrical stanchion holding a central seismic mass, flanked by two piezoelectric plates. This assembly is clamped rigidly by the cover. To ensure optimum accuracy and reliability, no bonding agent other than molecular adhesion is required to hold the assembly together. The ThetaShear design provides for a combination of highest measurement stability, excellent sensitivity-to-weight ration and low sensitivity to extraneous environmental effects.

A remarkable feature of the ThetaShear principle is the fact that the transverse resonance frequency is always outside the 10% frequency limit. This ensures minimum interference from orthogonal vibration components in the useful frequency range of the accelerometer. The ThetaShear design also provides excellent immunity to other environmental effects such as base strains, magnetic sensitivity and acoustic fields.

Brüel & Kjær

Figure D.11 Specification sheet one for Bruel and Kjaer accelerometer

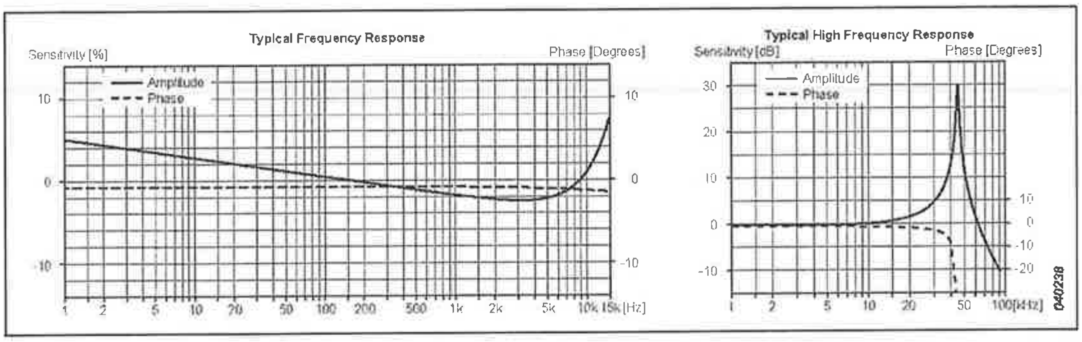
Fig. 1
Dimensions of Types 4500 A and 4501 A



Calibration

The sensitivity given in the calibration chart has been measured at 159.2 Hz with an acceleration of 10 g. For a 99.9% confidence level, the accuracy of the factory calibration is ±2%.

Fig. 2 *Typical amplitude response of Type 4500/4501 A*



Mounting

Special effort has been put into making mounting as flexible as possible. The accelerometer housing has slots that allow the use of mounting clips. The accelerometers can be easily fitted or removed to or from a number of different test objects.

There are three major mounting possibilities:

- The mounting clips are glued to the object, or fitted with double-sided, adhesive tape.
- A mounting clip with thick base can be modified, before use, to suit the mounting surface on the test object.
- A mounting clip with swivel base an a Spirit Level which makes it easy to align the accelerometer in order to retain the co-ordinate system.

Common Specifications for all Plastic Mounting Clips

Temperature range:	–54° to +50°C (–65° to +122°F)
For brief use, <1 hour:	–54° to +80°C (–65° to +176°F)
Maximum acceleration:	10 g peak (Perpendicular to mounting surface: 70 g peak)
Material:	Glass reinforced polycarbonate

Figure D.12 Specification sheet two for Bruel and Kjaer accelerometer

D 1.6 Microphone specifications for centrifugal force experiment

Attributes	
Search by product type	Microphones
Type	Electret Condenser
Impedance	600Ω
Frequency Response	80 - 13000Hz
Sensitivity	-61dB ±3 dB
Lead Length	5Mts

Figure D.13 Specification sheet for microphone used in centrifugal force experiment.