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DEPARTMENT OF PHYSICS

Student perceptions of the introductory physics laboratory: an exploratory study

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Munene Tlowana

7 December 2016

Abstract

The laboratory environment can prove to be a complex space, with its potential to foster scientific sense making abilities in students. One cause for concern is the frequent physics tearoom discourse that students do not like physics laboratories. However, before attempting to address this issue, it is necessary to establish to what extent it is true and then to probe the issues that might underlie such perceptions. The present study, part of a larger program that is aimed at probing student views with regard to the lab experience, describes (a) the development of an instrument that probes students' perceptions of lab engagement and (b) the results of a selected subset of the data as detailed below. A written instrument, the Physics Perceptions Lab Questionnaire (PPLQ), was designed to probe the following five areas: expectations of labwork, enjoyment of labs, the perceived degree of personal learning that took place, the perceived association between lectures and lab activities, and views about the relationship between experiment and theory. Each of the five questions that made up the PPLQ was constructed in the form of a debate in which different views were declared. Thus, the data that ensued were of two types: (1) a Forced Choice Response (FCR), and (2) a Free Writing Response (FWR). The FCR data were analyzed by tallying the various choices made for each question, while the FWR data were analyzed using a grounded approach.

The PPLQ was administered to 100 first year physics students at the University of Cape Town, after they had completed four weeks of the lab course. The focus of the present work is on the results obtained for the (a) Enjoyment and (b) Learning probes, and thus the analysis and results of the FWR data are limited to these two questions. The FCR results of the two probes on which the present study is focused (Enjoyment and Learning) indicated two opposing trends. While the majority of respondents felt that they had indeed learnt a great deal from the labs, this largely positive outcome for learning did not translate into a positive perception of enjoyment of labs. In contrast, the majority of the respondents indicated that they had not enjoyed the labs.

The grounded analysis of the accompanying FWRs led to the emergence of 15 reasoning categories. The categories are grouped according to their nature of being *intrinsic* and *extrinsic* to the laboratory task and also translate to being internal and external to the students' locus of control. In addition, each individual reason that was provided indicated a Positive (P) or Negative (N) Impact on engagement. The data were thus also coded for P or N impact. To improve the quality of engagement would thus require a collective effort that takes into consideration the link between cognition and emotions along with framing, as they encompass together the issues intrinsic and extrinsic to the lab task.

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1. Introduction

1.1 Background

Experiment is a key component of physics. Thus, laboratory work is usually regarded as an essential component of the introductory physics curriculum. Apart from the possibility of showing the link between experiment and theory, the argument has also been made that physics laboratories can serve as a platform for enhancing broader scientific skills and thinking abilities. While a large amount of research has been carried out by the Physics Education Research (PER) community, this has focused primarily on issues around student learning with regard to conceptual understanding of content areas (see for example Docktor & Mestre (2014)). However, over the past few years the lack of research into issues pertaining to laboratory work has been recognized, not only at first year level, but also beyond. Among some of the more recent studies over the past decade are those of Trumper (2003), Etkina et al. (2006), Zwickl, Finkelstein (2013), and Moore et al. (2014). In addition a report on labs was commissioned by the American Association of Physics Teachers on which the AAPT Subcommittee on laboratories reported in 2014.

A number of recent forums have also highlighted lab teaching. For example, the theme of the 2015 Physics Education Research Conference (PERC) was “A critical examination of laboratory centered instruction and experimental research in physics education.” At the conference, it was also pointed out that there was a “lack of research into lab-centered classrooms and undergraduate research”. Another initiative that is devoted to issues beyond first year labs is the Advanced Laboratory Physics Association (ALPhA), which was founded in 2007 and is “dedicated to advanced experimental physics instruction”.

Regardless of the level of the lab course, three main components that can usually be identified with regard to the actual activities that take place: engagement with apparatus, data gathering and analysis, and reporting of observations and findings. However, depending on the purported purpose of a particular laboratory, the emphasis placed on each component of activity and the way in which the overall purpose is framed can differ markedly.

1.2 Aims and purposes of introductory laboratory work

Both at first year level and beyond, a key issue that has a long history is what purpose a laboratory course is meant to serve (Michels 1962; Toothacker 1983). In short, the two main aims that are debated are laboratory work as (1) a vehicle for teaching experimentation and (2) a means of underpinning the conceptual understanding of theory. The way that this debate has manifested itself has been the subject of many investigations. For example, Read (1969) used a number of studies to extract and compile a list of purposes for introductory laboratories. The studies covered a wide range of sources ranging from physics to more general areas in science education. Based on his findings, he concluded that there appeared to be three main purposes of laboratories, namely, "*to teach the correct scientific attitudes towards experimental work, to teach the use of standard techniques and apparatus, and to illustrate lecture courses*". Read suggested that, of the three purposes, the last-mentioned purpose should be relegated in favor of the first two (Read 1969).

Almost three decades later, in 1997, the American Association of Physics Teachers (AAPT) committee on laboratory released a public policy statement reviewing goals for first year physics laboratories. There was general overlap between Read's findings and the AAPT (1997) recommendations, as can be seen from the AAPT document, which stated the first two goals in the following terms: ***"****The Art of Experimentation: the introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigation,* and *Conceptual Learning****:*** *The laboratory should help students master basic physics concepts".* One new suggestion by the AAPT was that *"The laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavours."*

Almost two decades, in 2014, later a follow up document from the AAPT was released. While the gist of the previous recommendations was maintained, it is interesting to note that the AAPT's 2014 recommendations now included the following aspects: "*Constructing knowledge – collect, analyze, and interpret real data from personal observations of the physical world to develop a physical worldview"* and *"Modeling – develop abstract representations of real systems studied in the laboratory, understand their limitations and uncertainties, and make predictions using models".*

It is clear that the present thrust is to give lab work a more central role in the teaching of physics, as more often than not lab work tends to be an add-on to the main part of a physics course which is focused on covering the theory. Thus, many laboratory courses at first year level tend to have limited time allocated in the overall curriculum and it is not uncommon for lab tasks to be presented in a cookbook style, the framing of which makes it difficult to achieve many of the goals stated in the AAPT 2014 report. While alternative ways of framing the traditional lab have been reported (Wieman & Holmes 2015; Holmes et al. 2014; Allie et al. 2003; Allie & Buffler 1998; Heller et al. 1999) this does appear to be commonplace.

It is clear that helping students to relate the theory to the actual phenomenon is important, but it is not easy to see how all the other goals relating to experimentation, modelling and critical thinking can be achieved in one introductory course. Thus, attempts have been made to separate out the goals of modelling and relating observations to theory. Two very different approaches that fall into the category of providing "conceptual scaffolding" are discussed below.

1.3 Laboratory approaches to scaffold conceptual understanding

Two different approaches can be identified that aim to provide scaffolding for the development of the theory in a more meaningful manner than simply asserting the concepts or the mathematical formalism. Both types of approaches involve the idea of classroom observation. In the first case computers play a central role in analyzing data that are collected while in the second case the emphasis is more on the modelling process. The differences between the two approaches can be seen through a brief summary of the following two well established programs (a) the Microcomputer Based Laboratories (MBLs) of Thornton and Sokoloff and (b) the Investigative Science Learning Environment (ISLE) that is centered around following the key steps of the "scientific method" in a laboratory setting.

One of the best-known approaches that exploit the use of computers is the MBLs (Thornton & Sokoloff 1990; Thornton 1987). Thornton argues that the traditional cookbook lab does not give students the authority to explore, measure and learn through observations of physical phenomena. This has the unfortunate result of students having limited control over their own learning. In the MBL approach, various sensors (motion, heat, force etc.) are used to gather data which is then fed into a microcomputer. This eliminates the difficulties associated with traditional ways of collecting data in the laboratories. The computer can then analyze the data and display various physical quantities such as distance, velocity, temperature curves etc. relating to the motion or heating of the object. At the same time, it gives students the possibility of plotting their own various graphs, giving them the flexibility to manipulate and think about the scientific process of interpreting models that represent the real world (Thornton 1987; Thornton & Sokoloff 1990). It is important to note that this approach differs from simulations as it involves interacting with the actual phenomenon in the real world.

An appraisal of this way of teaching is provided by Trumper (2003) as follows: "*The microcomputer-based laboratory can help to realize the previously defined constructivist principles of teaching and thus comply with the laboratory goals as defined by the AAPT (1997). It can make physics more understandable and appealing to the increasingly large numbers of students and future citizens. Universal access to this computing methodology can considerably increase the number of students who learn physics by doing physics and not just by hearing about it [physics concepts]*."

The Investigative Science Learning Environment, a curriculum commonly known as ISLE (Etkina & Heuvelen 2007), highlights the process of experimentation for the role it plays in "construction" of physics knowledge (theory). Starting with direct classroom observation and ending with theory is at the center of the approach which is based on a simplified version of the steps often associated with the "scientific method". In summary, each conceptual unit taught in an ISLE physics course follows a cycle with "*sequences of observational experiments, finding patterns, explaining patterns, testing and applying at a qualitative level and then at a quantitative*". Unique to this process and reflective of the primary goal of ISLE – constructing knowledge like a physicist – is that the cycle affords students the authority over their work with provided scaffolding that is reflective of "*how they [students] know what they know*" (Etkina et al. 2010; Etkina & Heuvelen 2007).

1.4 Traditional labs

While there are many innovative approaches to teaching physics that can have non-theory components, most physics courses that have a lab component do so as an activity separate from the main lectures. Such lab courses can also vary in the way that they are implemented, and a number of different approaches have been reported, including discovery based labs, closed versus open ended labs and problem based style laboratories (Kung 2005; Allie & Buffler 1998; Heller et al. 1999), authentic labs etc. However, more commonly, separate first year lab courses tend to follow what is often referred to as a "traditional" approach. While the implementation of such "traditional" labs may vary between different first year physics courses, and also from university to university, the following broad description serves to characterize the general practice.

Lab sessions take place in a specially designated space and at particular times outside of lectures. Furthermore, the lab tasks space is associated with a detailed instructional style that requires students to follow a sequence of steps to achieve a specific aim via a prescribed method. The output from such lab exercises varies from short hand-ins to full lab reports where the details of what took place during the session are reported. Full reports usually have sections entitled Aim, Apparatus, Method, Results and Conclusion. Many courses also include uncertainty analysis to some degree. In some courses, this might only involve identifying factors that could have affected the result, while in other courses a more rigorous treatment of uncertainties is required.

The present work involves looking at aspects of a "traditional" laboratory course which is part of a non-major physics curriculum at the University of Cape Town. A more detailed description follows in section 1.7.

1.5 Studies involving aspects of first year labs

Compared with the body of literature into student understanding of various content areas in physics, there has been relatively little work that reports on the various aspects of laboratory work. The research studies can be grouped into two broad categories. In the first category are those that look at student understanding of specific skills and processes that are meant to be developed as part of the course. These include student understanding of measurement and uncertainty, and lab report writing. The studies can be carried out using pre and post-tests using a written instrument, analyzing student writing or by interview. The second category includes issues pertaining to social interactions in the lab (student-student, tutor-student), student perceptions of the lab experience and student views about experimentation. Two types of studies can be carried out. The first involves probing student and/or tutor perceptions using the methods noted while the second involves direct observation of the processes and interactions.

With regard to studies that look into what has been learnt, the area of student understanding of measurement and uncertainty has received a fair degree of attention. Studies that look at this aspect have been carried out across the world (Wieman & Holmes 2015; Lippmann Kung & Linder 2007; Lippmann 2002; Holmes & Bonn 2013). The most important contribution to the area has been work carried out by the UCT-UoYork (University of Cape Town – University of York) collaboration, starting with Allie et al. (1998). The monograph published by the group Campbell et al. (2005) and the more recent paper of Volkwyn et al. (2008) both contain a large number of references that detail this area.

For his thesis, Gresser (2005) observed students learning through the dynamic nature of group interactions in the physics introductory lab. The lab had undergone major reform from a traditional cookbook style (see Lippmann (2003) whose thesis documents the details of the reform), where they eliminated the lab manuals. The unconventional framing of the lab task fostered effective social interaction that played a role in “initiating, negotiating, and carrying out … epistemic games”, which are meaningful cognitive processes over the lab task that improved sense making episodes in their interaction. Over the years, education psychologists have developed mental models that illustrate students’ cognitive process when learning science. Although such models, particularly developed for physics laboratories (see examples illustrated in Fearon (2014) thesis), are recommended for success, Fearon reports that students develop their own strategies when dealing with a lab task, which are not necessarily described consistently by those in the literature.

Students performing an experiment in a physics lab share some of the elements of a practicing physicist. This is evident from the core purposes stipulated previously, which significant aspects of experimental physics can be taught at introductory level. Holmes et al. (2014) reported no negative shifts of attitude in their transformed labs (Structured

Quantitative Inquiry lab (SQILab), see (Holmes & Bonn 2015) for description) where the learning goals “focus on understanding the process of science through reflection, iteration, and improvement”. On the other hand, students who went through the former lab using E-CLASS measured a “significant negative shifts in attitudes in the traditional course” compared to that found in the transformed course.

Apart from students’ attitude towards experimental work and science in general, there are few studies on lab work that explicitly probe “lifelong learning skills”. One lab course that is designed to also provide such skills is “Intro to Measurement” (Albanna et. Al. (2013)). Gandhi et al. (2016) unequivocally implemented student reflections that probed aspects such as self-compassion and courage, to highlight a few, that are at play through laboratory practice in his course.

1.6 Studies that relate to student perceptions of the lab experience

As the focus of the present work is on perceptions of students with regard to what they experience, this section takes a closer look at some related studies that have been carried out.

“Perception” is defined in the Merriam-Webster dictionary as “the way you think about or understand someone or something; the ability to understand or notice something easily; the way that you notice or understand something using one of your senses”. In this sense the perception about some variable is person bound and can differ from person to person and at the same time attribute different meanings and experiences of a phenomenon to the individual. Any study that seeks to understand to any degree students’ experience of the laboratory, their attitudes about science and the like, speaks directly to students’ perceptions. Thus, the broad scope of the present work probes expectations, views and attitudes.

One of the more well-known instruments that have been used in physics courses is the Maryland Physics Expectations survey (MPEX) which was developed in 1992 by the Maryland PER group. The MPEX instrument probes the attitudes, beliefs, and expectations that are deemed to have an effect on how students approach learning in an introductory physics course (University of Maryland PERG 1997). Around the same period that MPEX was developed – between 1993 and 1996 – Ibrahim Halloun along with

David Hestenes and the Modeling Research Team at the Arizona State University produced another instrument, “Views About Sciences Survey (VASS),” that probes students’ perceptions of the nature of science. This was in response to one of the research findings that shows the inconsistency of science beliefs between students and scientists. The Epistemological Beliefs Assessment for Physical Sciences (EBAPS) is also a forced-choice instrument that probe students’ perceptions of physical sciences- physics, chemistry and biology (Elby et al. n.d.). While EBAPS probes students’ epistemology at a deep level, it is difficult to analyze and interpret the data. In addition it has been shown that a number of questions are easily misinterpreted in the South African context, leading to completely incorrect results (Nwosu 2012).

Drawing on the experience of the three instruments, the Colorado Learning Attitudes about Science Survey (CLASS) was developed to probe student attitudes. Owing to the availability of having the data relatively easily analyzed, and because of the rigorous way in which CLASS was constructed and validated, it has been widely used, not only in physics but also in other areas of science at university level (CLASS-Phys, CLASS-Chem and CLASS-Bio). However, none of the instruments that have been mentioned are directed to probing the lab context, and while there may be some value in using these instruments, it is not clear that student views and attitudes pertaining to the theoretical aspects of physics and physics teaching will in fact extend to the physics lab context. The need for extending the scope of attitudinal perspectives in the context of *experimental* physics has recently led to the development of E-CLASS (The Colorado Learning Attitude about Science Survey for Experimental Physics).

The traditional lab context differs from the other aspects of the physics curriculum in several ways. The lab is a more complex environment and requires negotiation on several levels to achieve the learning goals. Students’ perceptions of the lab experience are strongly dependent not only on prior knowledge but also on how the immediate social aspects intersect with the various elements of the laboratory course, including the apparent purpose. As noted above, E-CLASS was designed specially to probe several aspects pertaining to expectations and attitudes in the lab context. Some of the aspects which are of interest to this study are affect, confidence, statistical uncertainty, and purpose of labs.

However, actual engagement in the laboratory involves several aspects that are not directly covered by E-CLASS. These include capturing some of the actual experiences that evolved from how the task is perceived and issues around carrying out the experiments. Few studies appear to have probed these aspects in detail. Among those that have are Sharma et al. (2014), Karalina & Etkina (2007), Hanif et al. (2009) and Lippmann (2002). These studies are discussed in detail below, as they are the ones that are most directly relevant to the present work.

A study that covers some of the aspects that are pertinent to the focus of the present work, and also involves a similar methodology as will be detailed in later sections, is that of Sharma et al. (2014). In their study, they evaluated the University of Sydney’s first year physics “innovative projects” module taken by three student cohort streams: advanced, technical and environmental. In their setting, students are charged with the design and experimental part including submission of a formal written report along with an oral presentation. This is a compulsory extension of their regular five session laboratory course, but it runs concurrently with the regular laboratory course and continues extensively for another four weeks after the usual laboratory course.

The objectives for the regular labs course are (1) “*The development of general experimental skills, including careful measuremen*t, *analysis and critical interpretation of experimental results*”, (2) *The capacity to work within a team*, and (3) “*The development of written and oral presentation skills.*” Unique to the projects module are two additional purposes, “*The undertaking of independent research and fostering of natural curiosity*” and “*The ability to design and carry out a simple scientific investigation*.”

Sharma et al. used two methods to collect data, a written survey and direct observation of some groups throughout all the sessions. The written questions consisted of both Likert scale and open-ended questions. The form in which the questions were structured – avoiding neutral options – forced some degree of commitment from respondents. Thus, for example, the options would be as follows: “1- very strongly disagree, 2- strongly disagree, 3- disagree, 4- agree, 5- strongly agree and 6- very strongly agree”. This allowed for the choices to be grouped into two mutually exclusive categories (positive and negative), in the present case being “agree” and “disagree”.

Of interest to the present work are the options that probed the enjoyment and learning aspects of the laboratory, written as “*taking part in lab projects… was enjoyable, was helpful in my learning of physics*”. 83.8% of the respondents were lumped under agree, a strong positive response pertaining to enjoyment of the projects module. For learning, 76.4% found the project module helpful in learning physics.

The survey further probed by including two free writing questions in the survey. These questions probed the best and worst aspects of the Projects Module as perceived by students from their experience of the module. Through an extensive process of coding the responses, with 8 and 9 categories in the best and worst aspects respectively, overarching themes emerged. These categories result from coding the data.

Including these two questions seemed to have strengthened the data and complemented the results of the tick a box. To illustrate the latter, I will show a significant contribution of the free writing response, which is the two questions regarding best and worst aspects of the projects module, to the tick a box question on learning. Here is an example of the analysis of the results regarding of the issues expressed in this question; a 'learning and understanding' theme emerged from students' written responses. Considering the statistical results against the results of the free writing response, 76.4% reported a positive experience, while there was a yield of more information about the learning in the projects module in which 22 of the issues mentioned (free writing responses) were coded best aspects and 12 were coded worst aspects. A more critical analysis of the Projects Module can follow from coupling the fixed-scale questions with free writing responses, as is shown in the following extract from the discussion and conclusion of this study.

"…worst aspects are concerned with the very practical concerns about equipment and the physical environment, time constraints and teaching staff. In summary, we conclude that the student perspective on the Projects Module is overwhelmingly positive, much more so than for the other more traditional parts of the overall laboratory experience… a substantial majority of students who responded in this study self- reported development of skills, such as critical thinking...We also conclude that the learning objectives for the Projects Module are mostly being achieved. There are, however, some aspects which could have been better."

Whereas Sharma and colleagues, whose study is mentioned above, developed categories from students' written responses, Karalina and Etkina (2007) applied existing categories which are three codes of the tree-triangle coding scheme developed by Lippmann (2002) who observed students engaging in the laboratory. Unique to Grounded Theory is its autonomy, the notion of knowledge grounded in data. Affirming this shared conviction, the existing three codes, namely sense making, logistic, and off task, of the tree-triangle coding scheme were modified subsequent to observing the different groups in the particular study. The final coding scheme applied to the three different laboratories investigated were included Sense Making, Writing, Procedure, TA's help and off-task.

The coding results from this study give an account of *"... Sense-making discussions [that] happened mostly in two situations: 1 when students were answering write-up questions; and 2 when students were having difficulty or doubts about the experimental procedure…"* Furthermore, the difference in students' sense making episodes is noted in the different laboratory environment in question:

"A detailed analysis of the time lines reveals that, in ISLE labs, sense-making discussions in type 2 situations were followed by procedural changes, i.e., attempts to improve and revise the experiment or carry out the next steps… In non-design labs, about 70% of such sense-making discussions led to asking a TA who provided an immediate answer…

We observed only one episode when students asked a TA which parameters to plug into a formula to analyse data and the TA made them derive the formula. Thus in ISLE labs students pose questions and answer them themselves, whereas in non-design labs students seldom pose their own questions and tend to search for answers from external authorities…"

Sense making regarding this study clearly refers to meaningful and meaningless engagement with the task at hand.

Contrasting results of the design and non-design labs shows that learning in the labs can be associated with meaningful sense making, which is a result of the way the laboratory task is structured. The ISLE lab with design forged meaningful sense making events unlike the other laboratories and so enhanced the learning in that laboratory setting.

Prior to the publication of the AAPT's most recent views on the purposes of laboratories, but subsequent to the publication of the last official goals in 1996, Hanif et al. (2009) developed a written instrument that was administered to a large fraction of first, second and third year physics students. The probe used the 1996 AAPT goals as a point of reference to inform them of students' perceptions of their laboratory experience. Forced choice questions were in the form of a Likert scale (Osgood et al. 1957), using a positive and negative point of view. The following terms were put to the students and they had to choose from a six point Likert scale placed between the words, indicating on which side their experience mostly closely lie.

*"Useful – useless, not helpful – helpful, enjoyable – not enjoyable, satisfying – not satisfying, understandable – not understandable, well organized – not well organized, best part of physics – worst part of physic*s."

The mere fact that students had to declare their enjoyment of the laboratories and also reflect on issues that fostered learning, enables one to study the social aspects of learning in physics laboratories.

"…responses of the students tend towards the more positive end in each item, although extremely positive views are not common …"

The researchers could make the above statement with a high degree of certainty because those were declared by respondents. This, however, merely gives us a quick indication of the mood in the lab. A deeper inference on students' perceptions would depend on how good a proxy the Likert scale is for the declared responses. To probe further this aspect of learning in the labs, question two, similar to the Likert scale in question one, lists a number of phrases and requires a tick a box of a five-point scale; strongly agree, agree, neutral, disagree, strongly disagree.

"Laboratory work helps my understanding of Physics topics………………………......

Discussions in the laboratory enhance my understanding of the subject………….

I only understood the experiment when I started to write about it afterwards…"

While the responses can easily be analyzed as reflecting either positive or negative experience, with respect to learning they also enhance the results pertaining to the former probe on learning. Below is a discussion that illustrates how results from one kind of probe compliment those of the other probe.

…responses are quite positive with the older students being more positive in quite a number of areas. For example, the older students are significantly more confident and less confused than the first year students. First year students, however, found tutorial questions before the laboratory were more helpful than the older students, reflecting their greater need and showing the value of pre-laboratory…

The survey also produced qualitative data; an open-ended question was included and followed by interviews with a selected number of students for further probing.

Students' perceptions of these lab experiences indicates, among other aspects, some of the challenges experienced in the laboratories. Among observed challenges is, for example, the issue of "time constraints" reported by Deacon & Hajek (2011). Such challenges are not limited to students; they are underlying nuances that the convener is responsible for in implementing the purposes of the laboratories as effective as possible. On average students in a typical first year traditional physics lab are required to perform a full experiment with complete analysis and a full write up in a single-day session of about 3 hours. The challenges can be somewhat overwhelming for the novice student relative to students with background experience from high school who might be familiar to some concepts of experimentation and hence somewhat confident with some of the instruments and terms used in the laboratory. While the purpose of laboratories might be clear to the instructor it cannot be assumed that these are shared by the students.

1.7 Brief description of first year physics labs at UCT

The Physics Department at the University of Cape Town offers a number of first year physics courses. Four main types of courses can be identified: physics major course, physics course aimed at non-physics science majors, engineering physics course and a medical physics course. About 1000 students attend one or other of these courses, and each course (apart from the medical physics course) involves students taking one afternoon lab per week. There is a single lab space in the department that can accommodate up to 300 students (working in pairs or in groups of three) at the same time. While each course convener decides on exactly which labs have to be done, the actual organization of the labs is overseen by a dedicated lab convener.

The learning materials for the course include a lab manual, a guide to measurement and uncertainty and a video. The lab manual contains a summary on the two types of uncertainty evaluation, its propagation and combining of uncertainties, analysis of graphs and quoting of the results and their associated standard uncertainty. It also contains an informal introduction of the experiments, familiarizing students with the theory behind the experiment and a procedure for performing the experiment (see Appendix 2). The guide book to measurements and uncertainty also provide information to report writing. A preparation talk is done through a YouTube video, which is available online to familiarize the students with what the apparatus looks like and how they work. In addition to the preparation tools is a pre-practical exercise students do before coming to the lab.

Extra help comes from three or four demonstrators, postgraduate students, and the lab conveners- lecture and the senior lab demonstrator- who are always present during the practical. Their role is to step in when students need assistance with the practical and guide students to engage meaningfully with the experiments. Demonstrators are also responsible for marking the student’s lab reports. Each lab is graded out of a total of 20 marks.

There is also a lab examination at the end of the first semester; where each is individually carries out a full experiment under exam conditions. Students are given questions of the “lab exam” week in advance of the assessment. The experiment set up is also on display a week prior to the lab exam but no data can be collected beforehand. The exam procedure entails that students collect data individually, analyze the data and write up a short report.

1.7.1 Details of lab work pertaining to the cohort of the present study

The course that is the subject of the present study is the non-major science course which is taken largely by biology and chemistry students. For most of these students, the first year laboratory was the first point of contact with hands-on experimental work. In week 1, prior to the first lab session, the materials described were handed out to the students. The sequence of afternoon sessions is described for the period prior to the study that forms the present work. Each lab session is three hours long and takes place every second week, alternating with theory tutorial afternoon sessions. Appendix 2 contains the lab manual with instructions for each of the experiments performed in the lab sessions. Following is a summary of each experiment:

Week 1: Hooke's law: Determining a spring constant

Students begin the lab by watching a short video that takes them through the process of collecting, tabulating and graphing the data. The first practical focuses on report writing; the structure required for the lab course with emphasis of tabulating data and drawing graphs. For the first lab session, no uncertainty evaluation is required; instead, students list the possible sources that would have contributed to the determination of the spring constant K.

Week2: Introduction to type A and type B evaluations of uncertainty

In the second lab session the students work through a worksheet exercise where their perceptions of reading a measurement from an instrument and how they quantify the measurand are assessed. Students also watch a video of an experiment contained in the worksheet, demonstrating the actual data collection for the purpose of illustrating sources of uncertainty that are evaluated using Type A and Type B methods.

Week 3: The Simple Pendulum

In addition to report writing and plotting of a graph, doing calculations with Excel and reporting of results are the edified skills. A short video similar to the one from the previous week is watched before students start collecting data. In this experiment only Type A uncertainty evaluation is performed. In previous lab sessions possible sources of uncertainty for the variable were investigated. In this lab the concept of an uncertainty budget is introduced.

Week 4: Motion under Free Fall

Presenting an uncertainty budget is reemphasized in the video shown during this lab session. The values of uncertainties are evaluated using a least squares fit using excel and linear fit.

Once all the lab sessions for the first semester are complete a lab exam is written.

1.8 The present study

As noted above, the present study forms part of a program that aims to try to understand the student experience of introductory labs in the physic department. While the previous section outlined a number of instruments and approaches that could potentially be used to carry out the study, it has become clear that local context plays a strong influence on the way in which the studies were framed and carried out. It was therefore decided that, while keeping the previous work in mind, it would be best to develop an instrument that was directed at the local context and drew on previous work that had been carried out by the UCT PER group. While the studies to date were in the area of measurement and uncertainty, the way in which the instrument and questions were designed had proved to be highly successful. Thus, a similar approach would be used to pilot and explore the area of interest. In the present work, the perceptions of students regarding physics introductory laboratories are explored across five areas using the framework developed by Allie et al. (1998)

1. Expectations of what the labs would be about (EXP)
2. The extent to which students enjoyed the laboratory course (ENJ)
3. Learning from a physics experiment perspective (LRN)
4. Relation between lectures and lab activities (LLR)
5. Relationship between experiments and theory (XTR)

The instrument that was developed to probe these areas is described in Chapter 2. However, in summary, two types of data came from the probes: the first which could easily be summarized in graphical form while the second required more detailed and intensive analysis. In the present work the results of the first type of analysis is presented for all five probes, while the second type of analysis is limited to the two questions that were deemed to be key to understanding the lab experience, namely, learning and enjoyment (areas 2 and 3).

2. Methodology

In the closing section of chapter 1, a detailed description of the intention of this study was made. By probing students' physics laboratory engagement, we intended to develop a conceptual understanding of students' perceptions of physics labs from an experience point of view.

To acquire some knowledge is the outcome of any laboratory exercise—for example, to foster scientific thinking abilities on measurements of data taken in the lab. Enjoyment on the other hand is an indication of students' satisfaction and appreciation of the experience irrespective of the difficulty or simplicity of the task. Thus these two perspectives, *enjoyment* and *learning*, are regarded as good indicators of students' engagement as experienced in the laboratory.

This chapter outlines the details of the steps that were taken to probe student's perceptions of the laboratory from the two perspectives, the method of gathering the data and the sample size as well as the analysis tool.

2.1 Development of instrument

A written instrument PPLQ (Perception of Physics Labs) was developed for the study, the main objective being to probe students' engagements in the lab. This was achieved by probing the extent to which students enjoyed the labs and the learning that that resulted in the lab course. The questionnaire included questions on enjoyment (ENJ) and learning (LRN). In addition to the two a direct question about expectations was included. Two more questions that indirectly probed students' expectation (EXT) of physics laboratories were included, one on the relationship between theory done in lectures and the lab course (LLR), and another on the relationship between experiments and theory (XTR).

The questionnaire was designed to gather qualitative and quantitative data. An important part of the data is the qualitative section, which includes the free writing responses (FCR) detailing the respondents' reasons for the views that are to be chosen in responding to the quantitative question. Juliet Corbin (2008) speaks of an important element for developing an effective instrument, framing the research question(s):

"... It is necessary to frame the research question(s) in a manner that provides the investigator with sufficient flexibility and freedom to explore a topic in some depth. ... While research questions in qualitative studies tend to be broad, they are not so broad as to give rise to unlimited possibilities…"

The final PPLQ instrument has five questions and a cover page detailing the way that the instrument had to be completed. While the Enjoyment and Learning probes were the two primary questions of interest for the study, all the questions followed the same form. This was done for two reasons: (a) so that students did not try to read into the purpose or relative importance of each question and (b) to try and get students to reflect on their answers rather than simply ticking boxes in a rote or "in the moment" manner. Even though present study will only rely on the analysis of the FCR's for each of the five probes and only the FWR's of Enjoyment and Learning questions, each probe still required a FWR. These questions allow students to express related issues and, where necessary, offload issues that relate to emotions about any discontent in the lab. The direct probe regarding students' expectations of the lab is listed as Question 1. Questions 2 and 3 are the two main questions for this study, enjoyment and learning respectively. The questions are numbered in such a way as to avoid offloading of issues in the first question.

Given the possibility that the first reaction to a lab questionnaire might simply lead to a student trying to offload issues of dissatisfaction about their experience, we avoided this by. In addition, it seemed to make more sense to place the Expectations as the first question. The questions regarding the relationship between lectures and the lab activity as well as experiments and theory were placed at the end as it was important the students engaged fully with the enjoyment and learning probes as early as possible.

Each probe was constructed along similar lines to previous work done by Allie et al. (1998) with their design of the Physics Measurement Questionnaire (PMQ) in which questions are presented in the form of a debate. In the case of the PPLQ each area of enquiry was probed with a single question. The questions were framed in the form of a debate where a discussion is posited followed by three statements (A, B, and C), which are the debate opinions regarding the posited discussion. The respondents are then requested to make a forced choice response (FCR) and subsequently give a reason for the choice they made (free writing response--FWR).

A distinct feature in the nature of the debate is the way the forced choice options are framed. The probe explores the extreme opposite end for each area (options A and B), forcing respondents to commit to a view or to select the third option C, which makes provision for respondents who might disagree with the strong opinions made. Option C allows for other perspectives to be stated. The instrument questions are designed in a similar manner to that described by Allie et al. (1998) where cartoon type figures are used for reasons that are explained. However, in the present case it was not felt that the cartoons would not be necessary even though they made a significant impact in the Physics Measurement Questionnaire (PMQ).

2.1.1 Final questions constituting the instrument (PPLQ)

The following is the list of the questions in the order that they appear in the instrument, the PPLQ.

Question: 1 [EXP]

A group of students discuss their expectations regarding the physics labs.

Student A says, “So far the labs have been what I expected they would be.”

Student B says, “I don’t agree! The labs turned out to be completely not what I expected.”

Student C says, “I do not agree with either of you!”

Question: 2 [ENJ]

Another group of students are debating how much they enjoyed the labs.

Student A says, “I really enjoyed the labs!”

Student B says, “I did not enjoy the labs in the least!”

Student C says, “I don’t agree with either of you.”

Question: 3 [LRN]

A third group of students argue about what they learnt.

Student A says, “I learnt a lot in the lab!”

Student B says, “No! I learnt very little in the lab.”

Student C says, “Hang on, I have a different view to both of you.”

Question: 4 [LLR]

Three students are arguing about the lab versus the theory part of the course.

Student A says, “I did not like the labs as they did not help us with lectures or problems sets”.

Student B says, “You are confused! The labs were not meant to do that in the first place.”

Student C says, “I don’t agree with any of you!”

Question: 5 [XTR]

A group of students disagree about the experiments and theory.

Student A says, “The main aim of experiments in physics is to prove the theory correct.”

Student B says, “No! The main aim of experiments in physics is to discover new things.”

Student C says, “I have a different view to both of you.”

Note that in each case the questions end with the following sequence:

1. With whom do you most closely agree? (Circle one)

A	B	C

2. Explain your choice in as much detail as possible.

Appendix 3 contains the complete structured questionnaire.

2.2 Student sample

The sample was made up of a subset of first year students[1], registered in the science faculty at the University of Cape Town, who wish to follow a career in any of the streams of chemical, molecular and cellular sciences, environmental and biological sciences. These science streams require students to take an introductory first year non-major physics course, PHY1031F. At the beginning of the year, the start of first semester, the students registered for the PHY1031F course attend a series of lectures, tutorials and laboratory work for six weeks. Five weeks into the course students write a test which is used to identify under prepared students who are likely to have difficulties in coping well with the pace and level of the course. Those identified will have the opportunity to decant into an extended two semester course, PHY1023, instead of PHY1031F that covers the similar content in one semester.

General content covered in this course includes vibrations and waves, properties of matter, and mechanics. Our interest for this thesis pertains to students' experiences of the laboratory component of the PHY1023F course. The decant students attend a total of four lectures per week, each running for 45 minutes per lecture with an additional 45 minutes' white board tutorial. They prescribe to College Physics: A Strategic Approach 2nd edition by Knight, Jones and Field as the textbook. Coupled with the lectures is a three-hour afternoon white board tutorial alternating weekly with a three hour laboratory session. The lab course covers a total of eight practical sessions with a full but simple report submitted at the end of each practical. The experiments covered over the lab course are; Hook's Law (where a spring constant is determined), An Introduction to Type A and B Uncertainty Evaluations, The Simple Pendulum, Motion under Free Fall, Simple Harmonic Motion, Air Track, Rolling or Sliding, Flywheel, and Waves on a Stretched String.

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[1] There was no statistical calculation for selecting the sample and the sample size. The group of students in question had completed the first few weeks of the introductory physics course for non-majors. At the end of the four weeks all students who have started an introductory physics course complete a test, the results of which are used to advise students to either remain in the mainstream course or to transfer into a slower paced course. The students in question are the latter group. One of the reasons for using this group as the target for the pilot study is that it is crucial from the purpose of developing suitable interventions, that the reasons for the performance in the first few weeks is well understood. Another reason is that it most likely that the widest spectrum of responses is likely to emerge from this group. The fact that the cohort in question was 100 in number was completely coincidental as this was in fact the number of students who in fact transferred into the slower paced course.
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2.3 Organizing the data

Each response set consisted of six pages comprising the cover page followed by the responses to the five probes. Each script was then allocated a respondent identification number (RIN), which was used in the analysis to track a set of responses from a particular respondent, while retaining the anonymity promised to respondents prior to participation in the study. The RINs were arranged in numeric order of 101 to 200 and also copied onto each page of each of the 100-response set. The staples were then removed from the scripts and each page then separated and sorted into individual questions. This resulted in 5 piles of 100 pages with a total of 500 forced choice responses and another 500 free writing responses. For data security, all the piles were scanned and copies were made. The original scripts were then stored.

The following chapters, 3 and 4, detail the manner in which the two types of responses were processed for analyses. The FCRs consisted of tallying the choices associated with each probe while the FWRs were analyzed using an approach suggested by Grounded Theory (Juliet Corbin 2008) and Phenomenography (Marton 1981) for categories of reasoning.

A grounded approach was felt to be an appropriate choice of method for analyzing the the written responses. This method has been previously tested with a research questionnaire compiled in a similar manner to the PPLQ (the Physics Measurement Questionnaire) and the analysis produced meaningful results. As part of developing the methodology for future studies, the present thesis was also felt to be a good a testing ground with regard to the viability of the approach. One of the reasons is that the students in question (see footnote on previous page) come from diverse backgrounds, including a large percentage for whom English is not a first language as well students who come from less well-resourced high schools. Thus, successfully developing the methodology for this cohort of students provides a testing ground in terms of whether the free writing produced can in fact be analyzed meaningfully by this approach. The full details of how the method was used are in chapter 4.

2.4 Protocol for administering the PPLQ

The PPLQ was administered to 100 physics first year students in a single cohort, described in the background of the study, at the end of the first semester in 2014. To make the participation of respondents as convenient as possible the questionnaires were completed immediately after the students had written the lab examination. Students were instructed to remain seated after they were done writing the exam. Immediately when the exam time had elapsed, with an introduction and a brief explanation of the research, students were asked to take part and complete the questionnaire.

While we used Allie et al. as a basis for carrying out the present study, the way in which the present instrument was administered differed from that described by them. In their case the PMQ was administered according to a protocol in which each question had to be answered in a particular order and could not be returned to. This was to avoid the possibility that a previous question would be answered differently after the student had seen the subsequent one. This effect was not a problem in the present study. In fact, the opposite effect was considered, namely, that students who had strong negative emotions about the lab might off load this at the first opportunity. Thus, if they disliked the lab very much and the first question involved learning it is possible that they would simply choose the option which most closely aligned with their feelings rather than aligning with their considered views about learning. The data would be difficult to interpret if this effect was significant. It was therefore felt that students should in fact be allowed to answer the entire instrument in whatever order they wished and also that they be allowed to return to previous questions. Hence, the order of the questions was such that the one about learning followed the one about enjoyment.

Respondents were also made aware of the anonymity of their responses and it was emphasized that open and honest responses would help improve students' future experience of the physics laboratory. In particular, it was guaranteed that the laboratory convener and demonstrators would not have access to individual responses. However, the reason for the request to fill in their student numbers on the questionnaire was to enable the researchers to contact the student in the event that further clarity of the responses was required. While it was not intended that this measure would be used, the accountability that was introduced maximized the chances that students would not simply answer the questions in a whimsical manner. All the questionnaires were completed within half an hour without any questions of clarity being allowed at any point while the questionnaire was administered. It also appeared that the students took the questionnaire seriously judging from the way they behaved while answering the questions. This impression was obtained from walking around the venue during this time. The students did not interact with each other during the time they were completing the questionnaire. This is ascribed to the fact that the post examination setting framed the behavior of the students. However, it is unlikely that students answered the questions as if it were an examination since the nature of the questions did not pertain to content issues.

All the scripts were collected and each script was kept intact as there was no way of identifying individual students other than by the first cover page. The process that was then followed is described in the following chapters.

3. Analysis of Forced Choice Responses

All the responses were collected from all students who took part in the study and were organized (as detailed in the previous chapter) as raw data to be processed for analysis. In this section I will present the process of capturing and analyzing the first part of the responses, which was the FCR.

A table was drawn on an excel spreadsheet to capture the FCR data. The excel software was primarily convenient its calculation functions, which were useful for processing the data. The data was captured onto the spreadsheet that consisted of a series of 6 columns as follows; Column 1 was used to record the respondent identification number (RIN) while columns 2-6 were used to capture the responses, A, B or C chosen for each question. A separate row was assigned to each respondent. Thus, the final spreadsheet consisted of 6 columns and 100 rows.

The data was then processed on a question by question basis. This resulted in 5 columns of data for each of the 100 students making a total of 500 entries. Spoilt data ensued in a few cases where more than one option was selected by the respondent, and in other cases no option was selected. In both instances the code U (uncodable) was recorded. The total number of U's was 9, making up 1.8% (9/500) of the data.

Table 3-1 shows the ensuing spreadsheet with each of the columns 2-5 labelled with a three letter abbreviation describing each of the probes: expectations (EXP), enjoyment (ENJ), learning (LRN), the perceived relationship between lectures and laboratory activities (LLR), and the relationship between experiments and theory (XTR).

Table 3-1: Forced Choice Responses (5 questions x 100 respondents)

RIN	Q.1 EXP	Q.2 ENJ	Q.3 LRN	Q.4 LLR	Q.5 XTR	RIN	Q.1 EXP	Q.2 ENJ	Q.3 LRN	Q.4 LLR	Q.5 XTR
101	A	A	A	B	A	151	B	B	B	A	U
102	A	A	C	C	B	152	B	B	A	A	A
103	B	A	A	C	C	153	B	B	B	B	A
104	A	A	A	C	A	154	B	B	A	A	C
105	B	A	A	B	B	155	A	B	B	A	C
106	C	A	A	C	A	156	A	B	B	A	B
107	B	A	B	A	A	157	A	B	C	B	B
108	A	A	A	C	A	158	B	B	A	C	A
109	B	A	A	A	A	159	B	B	C	A	A
110	C	A	A	A	U	160	B	B	C	A	A
111	B	A	C	B	C	161	A	B	A	B	B
112	A	A	A	C	A	162	A	B	A	C	A
113	A	A	A	C	C	163	B	B	B	A	C
114	A	A	A	C	C	164	B	B	B	A	C
115	A	A	A	B	C	165	C	B	C	C	C
116	B	C	A	C	B	166	A	B	A	C	C
117	A	A	A	B	A	167	C	B	C	A	C
118	B	A	A	C	C	168	B	B	B	U	U
119	C	A	A	B	A	169	A	B	A	B	B
120	B	B	A	B	A	170	A	B	B	C	U
121	A	A	C	B	C	171	B	B	B	U	A
122	A	A	A	B	B	172	A	B	B	C	B
123	C	A	C	C	C	173	A	C	B	C	A
124	A	A	A	C	C	174	A	C	C	C	A
125	A	A	A	C	A	175	C	C	A	C	B
126	B	A	A	A	B	176	A	C	A	A	A
127	A	A	A	B	B	177	A	C	A	C	A
128	A	A	A	B	B	178	C	C	A	A	C
129	B	A	A	B	A	179	A	C	C	A	A

130	A	B	A	C	A	180	A	C	B	C	C
131	B	B	B	A	A	181	A	C	A	C	B
132	A	B	B	C	B	182	B	C	B	C	A
133	B	B	B	A	A	183	A	C	C	B	A
134	A	A	C	C	B	184	B	C	A	B	C
135	B	B	B	A	C	185	A	C	A	B	C
136	B	B	C	A	A	186	A	C	A	A	C
137	B	B	U	C	A	187	C	B	C	B	C
138	B	B	A	A	A	188	A	C	A	C	A
139	B	B	B	B	C	189	C	C	C	C	C
140	A	C	A	C	A	190	A	C	A	C	C
141	A	B	B	B	C	191	A	C	A	B	C
142	B	B	C	A	B	192	C	C	C	B	C
143	A	B	B	B	B	193	A	C	A	B	A
144	A	B	B	C	A	194	A	C	A	B	B
145	C	B	C	A	C	195	B	C	B	C	A
146	B	B	C	B	A	196	A	C	A	B	C
147	C	C	C	C	A	197	A	C	A	B	A
148	B	B	A	C	C	198	A	C	C	B	C
149	B	B	A	A	A	199	A	C	A	B	A
150	B	B	B	A	A	200	B	C	U	U	C

3.1 Tallies of FCR data

The full data set shown above in Table 3-1 was summarized by tallying each column. All the calculations that included percentages and counts together with the plotting of graphs were done using the Excel software. The tallies of all three options for each probe are shown in Table 3-2 below. The codes A, B, and C correspond directly to options provided in each probe. While all the responses from the Expectations and Enjoyment probes were assigned A, B or C codes successively, the code U was applied in questions 3, 4 and 5 where the A, B or C responses could not be clearly identified as a result of an unclear mark or no mark on the FCR "tick a box".

Table 3-2: Tallies of options A, B, C or U codes of the FRC for each probe.

Probe	**Tallies:** A	**Tallies:** B	**Tallies:** C	**uncoded**
Expectations (EXP)	50	37	13	0
Enjoyment (ENJ)	28	42	30	0
Learning (LRN)	52	24	22	2
Lectures and laboratory activities (LLR)	26	32	36	6
Experiments and Theory (XTR)	43	19	34	4

The frequency distributions for each probe are shown graphically in Figures 1 to 5 below. The y-axis shows the respondent percentage while the x-axis indicates the response choices A, B and C. It should be noted that the tallies of the U code, although included in the calculations, are not plotted on the graphs because they have relatively low values. The main features of each graph are briefly discussed below the graph. The data includes error bars (95% confidence intervals) that were calculated for completeness (see Appendix 5).

The tallies quantify the number of students in the laboratory who express the different views expressed through each option. The FWRs will refine the strong opposing options expressed by students' choice between option A and B by determining whether the reasoning of each choice is a good enough proxy for the option chosen. As important as the two analyses would be in strengthening the results of the tallied data, the main interest for this study was to establish existing issues that had an effect on the enjoyment and learning in the laboratory. Hence the FCR analysis for this thesis does not continue beyond representing the tallies graphically.

Common to all histograms is the 95% confidence interval error bars, indicating statistical difference in proportions. Inference regarding significant statistical difference between the options A, B and C in Figure 3-1 to Figure 3-5 quantify students’ experiences based on the statements made for each option. However, given the important outcome of the necessity to consider students’ subsequent reasons for the choice, the error bars become useful for comparison of data taken in future studies of the same laboratory, especially where some changes have been made in a response to findings from the current study.

The expectation probe is one of the three additional probes in the PPLQ instrument designed to probe the outcome of the engagement with laboratory activities. The debate probes directly students' expectations of the laboratory by questioning the extent to which their expectations matched what they experienced in the laboratory course.

Figure 3-1 shows a plot of the tallies of the FCR options A, B and C chosen. It can be seen that most of the respondents (50% precisely) chose option A with the view that, "So far the labs have been what I expected they would be". On the other hand, just over a third of the cohort (37%) disagree with that assertion, choosing option B that, "I don't agree! The labs turned out to be completely not what I expected". The lowest (13%) number of respondents chose the statement in C that "I do not agree with either of you!", indicating that they had some other view(s), which we can suppose were different and not close to either of the two options expressed in A and B.

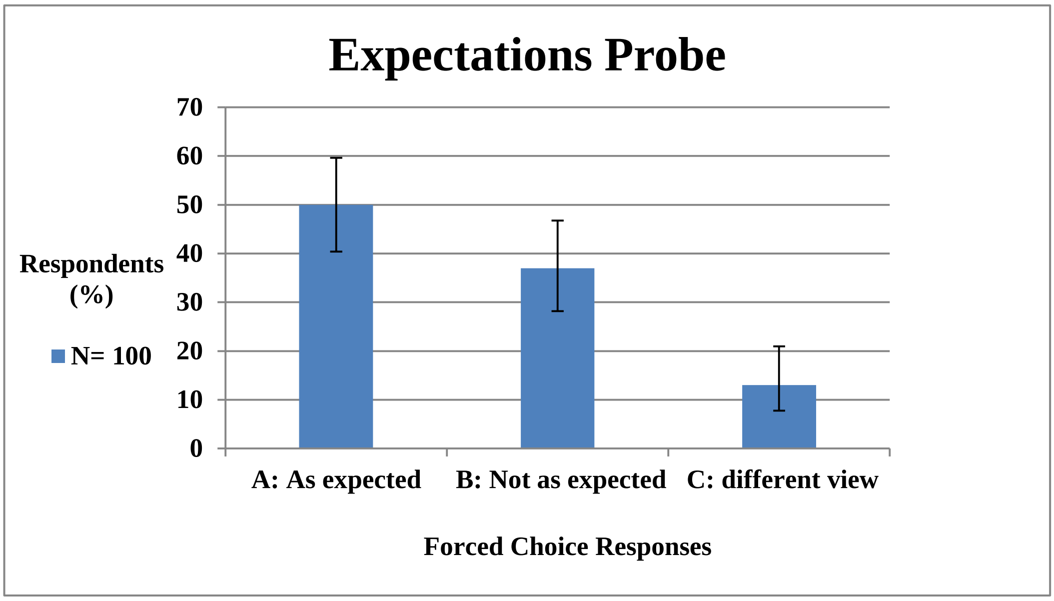

Figure 3-1: The distribution of the FCRs for the expectations probe. The error bars included indicate 95% confidence interval for proportions.

The enjoyment probe is one of the main perspectives used in the study to explore perception of introductory labs. The question attempts to probe the extent to which the students enjoyed the labs by phrasing the strong opposite debate statements (A and B) but also includes a neutral option C where diverse views can be expressed.

The graph in Figure 3-2 shows the frequency distribution of results from the Enjoyment question. It is interesting to note that the most prominent choice, just under of half the responses, was associated with the strong statement of B, that, “I did not enjoy the labs in the least!”, while the least selected view, with just over a quarter (28%) of the respondents is that of option A, “I really enjoyed the labs!”. However, it is noteworthy that a significant proportion of respondents, close to a third (30%), chose option C, that “I don’t agree with either of you”. The comparatively large percentage of respondents who chose option C (over A and B) supposes a limitation to the inference that can be made from the FCR about the extent to which students enjoyed the labs; a significant number of responses (option C) are not represented in the explicit binary inference that can be made that students enjoyed or did not enjoy the labs.

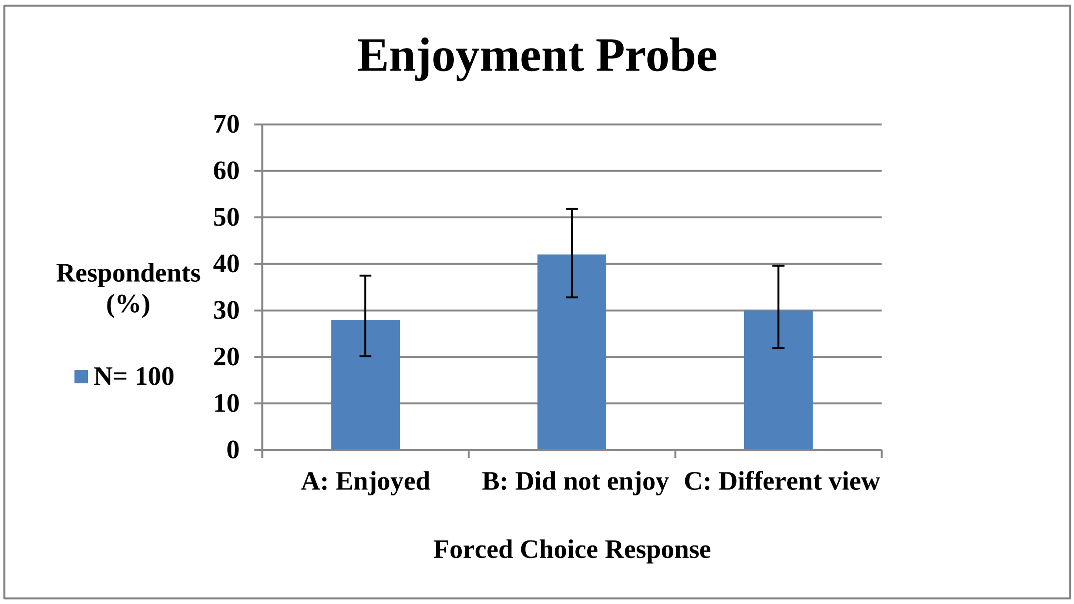

Figure 3-2: The distribution of the FCR obtained from the Enjoyment probe. The error bars indicate 95% confidence intervals for proportions.

The learning probe is the other main perspective of the study with which students' perceptions are explored. Again a binary option probing style is used, similar to the enjoyment probe, with two strong opposite statements posited in the debate. Figure 3-3 shows the results of the FCR tallies for the Learning probe. About half (46%) of the responses were almost equally (24% and 22% respectfully) spread between the options B, that, "No! I learnt very little in the lab", and C, that, "Hang on, I have a different view to both of you." The rest of the responses tallied close to half (52%) are associated option A, that, "I learnt a lot in the lab!". Note that the results represented on the referred graph are only 98% of FCR responses. The column for two of the responses coded U for reasons mentioned in the text is excluded on the graph because of its supposed insignificant frequency as well as our interest in those who choose either A, B or C. However, the 95% confidence interval calculations include all the 100 responses.

Considering the overall pattern of responses to the previous enjoyment probe, it is interesting that half of the respondents chose option A. The Enjoyment and Learning free writing responses are explored in more detail.

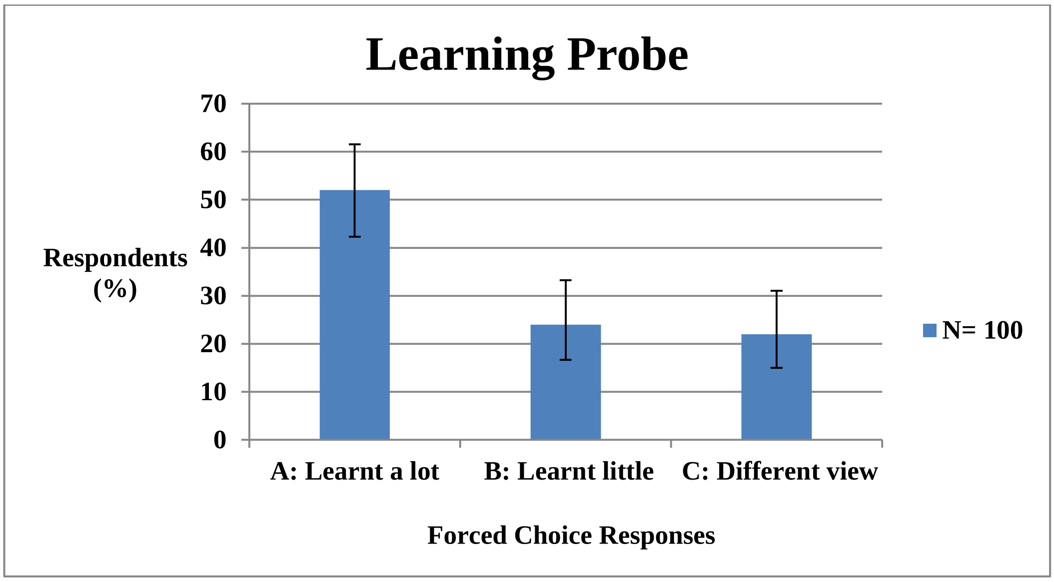

Figure 3-3: The figure shows the tallies of the FCRs for the Learning probe. The U (uncodable) category is excluded from the plot but included in the calculations.

Figure 3-4 represents the distribution of responses of the probe on the perceived relationship between the lectures and the activities in the lab. This is the second additional probe that indirectly probe students' expectations for the lab, particularly the role of experiments in the physics course. The option with the most frequency of just above a third (38%) is of respondents that chose option C with the statement "I don't agree with either of you [views A and B]". Slightly less than those who chose the option C, 32% of respondents chose option B, that "You are confused! The labs were not meant to do that in the first place [help with lectures or problem sets]" while about a quarter (26%) chose the conflicting view in option A that, "I did not like the labs as they did not help us with lectures or problems sets". The distribution shows small variations in frequency across the three options.

Again only 96% of students are accounted for in the three options presented in the chart below. The plot for the 4% of responses that could not be coded for reasons stated previously is not included, while the percentage and error bar interval calculations include the uncodable results.

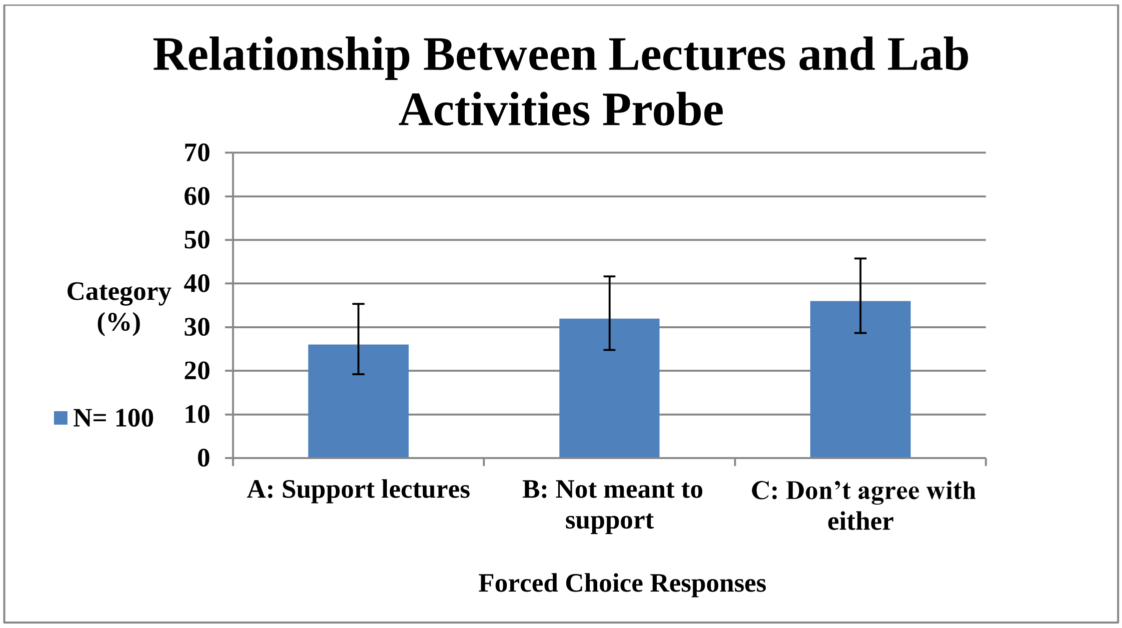

Figure 3-4: Histogram of tallies of the FCRs for the probe regarding students' perceived relationship between lecture work and laboratory activities. The U (uncodable) category is excluded from the plot but included in the calculations.

The graph in Figure 3-5 shows the distributions for respondents' FCRs regarding their views on the relationship between experiments and theory in physics. The greatest proportion of respondents (44%) agreed with the view of option A that, "The main aim of experiments in physics is to prove the theory correct". Slightly more than half the respondents (19%) chose option B, opposing option A that, "No! The main aim of experiments is to discover new things". Interestingly about a third of the respondents had a different view to either discovering or proving, and chose option C. There is no significant statistical difference for proportions in A and B with respect to those who chose option C. The relatively high percentage of respondents who chose option A is noteworthy, considering that they agreed closely with the view that the aim of experiments is to prove theory correct, which is interesting because none of the lab experiments involved proving theory correct.

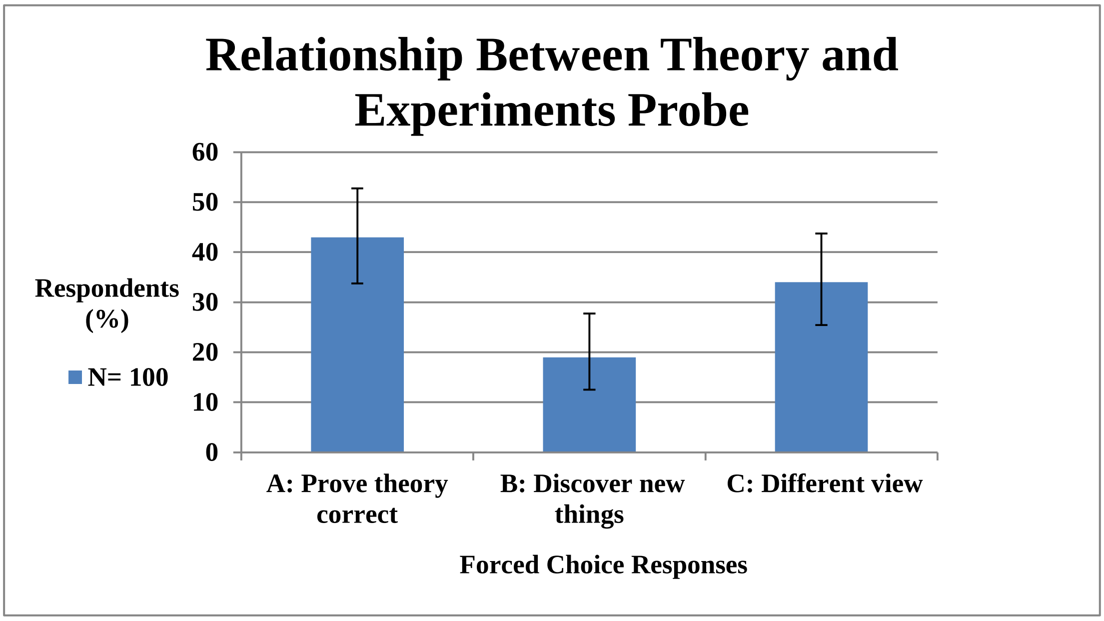

Figure 3-5: The figure shows the distribution of the FCRs for the probe regarding the relationship between theory and experiments. The error bars indicate 95% confidence interval. The U (uncodable) category is excluded from the plot but included in the calculations.

FCRs for all five probes were tallied and presented graphically in this section. While the data provided interesting information, the detailed reasons for students choosing the particular option are not apparent. This is particularly important for the questions that probe the enjoyment and learning aspects of the lab experience which are regarded as the core questions of the instrument (PPLQ).

4. Analysis and Results of the Enjoyment and Learning FWRs

As noted in Chapter 3, these two probes (Enjoyment and Learning) are regarded as important indicators of student engagement in the laboratory and understanding students' reasons for FCR's is thus a key part of this study. For this reason, Chapter 5 details the analysis of the Free Writing Responses (FWRs) for these two probes. However, in addition to this aspect of the work it is of further interest due to the intriguing nature of the comparison in that the results for the two probes do not appear to be commensurate with each other. In more detail: 28% of the respondents chose the strong view (B) that they did not enjoy labs in the least, yet 52% opted for the view that they learnt a lot. The analysis of the FWRs is thus important to answer the following two questions: (1) what are the main categories of reasoning that underlie the responses, and (2) to what extent are the FCRs good proxies for the underlying reasoning patterns that emerge.

4.1 Development of the coding scheme

In this section the process for developing a coding scheme for the qualitative data collected with the PPLQ (Physics Perceptions Lab Questionnaire) is detailed. Methods associated with Grounded Theory (Juliet Corbin 2008; Saldana 2009) are used for most of this exercise. A coding scheme comprises codes which are a shorthand description of the categories that are developed from salient key phrases of visual data. In this case, Key Ideas captures the essence of student reasoning expressed in the FWRs. The codes were developed from a fraction of the sample of responses of the enjoyment and learning probes separately. Each code represents a category of reasoning captured in the data and then coded on the full data set. The actual way in which the analysis processes took place is detailed throughout the sections that follow in this chapter.

From the sample 20 FWRs per probe were randomly selected. Each piece of writing was then carefully read. A spreadsheet was then used to record a summarized version of the original written response, i.e. as far as possible the actual words used were recorded without making any substantive changes or inferences. In general, the changes were confined to typographical corrections, removal of personal pronouns (in some instances they were not removed for the sake of retaining grammatical sense) and minor shortening of rambling sentences. In addition, semicolons were used to separate out what appeared to be separate issues. Below are two examples of the original (typed but close to verbatim) student responses together with the summarized version.

Enjoyment Probe: RIN 116

"I enjoy some parts of the labs and others are stressful and hard to do. It becomes very stressful when the time is about to run out and I am no near finishing. Sometimes when I understand what I am doing enjoy it but since I am slow at writing I end up running out of time."

Summarized version:

Enjoy some parts; others stressful and hard; stressful if time runs out and not near finishing; enjoy when understand; slow at writing so run out of time.

Learning Probe: RIN 126

"My choice is A because I'm one of those people who learn a lot. I get to know the difference between different variables and come up with solutions for particular problems. And also because of the experiments I learn new stuff."

Summarized version:

One of those who learn a lot; Get to know difference between variables and come up solutions for particular problems; because of experiments—learned new stuff.

Column 3 of Table 4-1 and Table 4-2 below show the results of this exercise for the 20 responses that were chosen for analysis of the two respective questions. The inter-rater agreement between my supervisor and me for this process was close to 100%. For every student writing we identified all Key Issues that were expressed by the respondent. These were then recorded in column 4. The inter-rater reliability for this step was above 90%. In all cases the disagreement was easily resolved after discussion. These two tables show results of the initial process described.

Table 4-1: showing 20 written responses for the enjoyment probe.

RIN	FCR	Summarized student writing: Enjoyment FWR	Key Issues
116	C	Enjoy some parts; others stressful and hard; stressful if time runs out and not near finishing; enjoy when understand; so run out of time.	Stressful when time runs out and the work not complete. Enjoys when the work is understandable
140	C	Most labs enjoyable but our experiments result in incorrect data which affects marks; otherwise nice “hands on” experience	Experiments result in incorrect data which affects marks Nice “hands on” experience
147	C	Do not enjoy it but do not dislike it.	Uncodeable
134	A	Really enjoy labs, because it helps understand the topic; also learn to apply the knowledge learned.	Helps understand the topic Learn to apply existing knowledge
129	A	Labs exposed us to technology we are used to for plotting graphs etc.; use laptops for watching videos and essays, nice trying something new (Excel which was nice); a bit tricky and confusing at beginning; nice knowing many ways of manipulating data for different outputs.	Technology exposure Applying technology to lab work Like Excel Ability to manipulate data-in various ways is nice
128	A	Enjoy labs, because it’s the real world of physics, see how things work; teach interaction with other students; listen and combine ideas to come up with solid conclusion, this helps think scientifically.	Appreciate physics phenomena Develops group interaction skills Encourages scientific thinking
126	A	Enjoy being in labs because of experiments done there; learn more stuff about physics and general science; get to explain things in own way and own scientific thinking; helps think beyond not just general but look at things scientifically.	Enjoy performing experiments Learn science and physics phenomena Able to explain scientific concepts
127	A	Enjoyed being in the labs; they are exciting since, learn more things and gain knowledge; create friendship on group discussions; get new ideas from students.	Learning more things Develop friendship from working in groups Learn through group work

Table 4-1 continues to the next page

187	B	People around doing new stuff (unfamiliar to the respondent); they don't wait for me to catch up; Pre-practical question don't help; Don't enjoy at all; don't even ask question because is awkward; calling demonstrators every time makes one [me] look stupid.	Group does not wait for me to understand
			Pre-practical question don't help
			Asking questions feels awkward
			Calling demonstrators constantly makes one [me] look stupid.
156	B	At first, labs seemed interesting until learning has marks, shift trying to understand what experiment is about, and to obtaining marks; labs less fun and become a burden. Those who never used labs before are disadvantaged, even with tutors there to help, since basics of labs aren't taught; learn by doing more experiments at cost of marks.	Obtaining good marks compromises the fun in learning
			Shift trying to understand the experiment to obtaining marks
			No lab experience is a disadvantage
			Learn by doing more experiments at cost of marks
157	B	Not particularly exciting since 10% is practical and 90% is writing report, working out uncertainties and drawing graphs	Not satisfied with 10 % allocated to Performing experiments
			Not satisfied with 90% consumed with the following: Report write up—unsatisfied about volume of work
			Uncertainty evaluations—unsatisfied about volume of work
			Data analysis- unsatisfied about volume of work
132	B	Statistical analysing of data and uncertainties are tedious and spoil excitement during practical; Understand the need to report results but uncertainty aspect is very complicated.	Tedious and complicated uncertainty evaluations
			Tedious data analysis
			Understand the need to report results but uncertainty aspect is very complicated

175	C	Enjoy practical with friends, finding relationships between things etc.; but don’t like Excel; although plotting graphs is very easy, equations are not.	Enjoy practical with friends Dislike Excel Plotting graph very easy Challenging calculations
120	B	Did not enjoy labs; because most time [I] didn’t know what to do; Instructions were not clear.	Most of time don’t understand unclear Instructions
118	A	Doing the experiment, trying to think about what other scientist before me were thinking is really amazing, get to understand scientist way of thinking, understanding and analysing data.	Appreciate scientists and performing the experiments Appreciate scientific thinking Comprehend data analysis
150	B	Very long; not enough time to do experiment and write a lab report.	Long lab session Not enough time to do experiment and write a lab report
106	A	Enjoy the labs; very interesting in terms of-confirming values we already know by doing experiments; Enjoy them because one gets to do things practically which helps understand things better and be able to explicitly explain things because one really understood.	Interesting to verify constant values by experiments Performing experiments cultivates understanding Understanding and explaining things better
170	B	Did not enjoy labs because of feeling lost; Reading lab manual does not even help, always lost; don’t enjoy at all; always feel dump in labs.	Confusion- feeling lost Lab manual—unhelpful always feel dump in labs
198	C	Sometimes, there are experiments that are tricky and very long; Experiments need a thorough procedure, [respondent] may take more time to finish.	long and challenging experiments Experiments require more details
173	C	Labs neither boring nor fun; Enjoy practical part, a nice different way of working; theory (write-ups) can get boring.	Enjoy practical part report writing can be boring

Table 4-2: showing 20 written responses for the Learning probe

RIN	FCR	Summarized student writing: Learning FRW	Key Issues
116	A	There is a lot learned in labs, like- doing theory part practically and understanding procedure involved.	Learnt to do theory part practically Learnt to understand procedures
140	A	Physics pracs show- there is more than one way of proving something (value of g) and tackling problem.	Various experimental methods Various approaches to problem solving
147	C	Don't learn a lot from labs because to achieve some practical requires certain amount of knowledge; however, practicals also helpful- they illustrate what we learn in lectures; help develop new skills.	successful experiments require prior knowledge Helps development skill Illustrates work done in lectures
134	C	It depends on the topic of experiment. When doing an experiment on certain topics, I tend to learn a lot more; If I understand the topic, I don't learn anything in the labs, whereas if I don't understand the topic, I learn a lot during the labs.	Learn more with unfamiliar concepts
129	A	Learnt lot of things, especially measurements; had no idea about uncertainty-now better understanding of what uncertainty is all about; Scientific reasoning improved; manipulation of equations help very much-evidence when stating a certain hypothesis.	Understand the concept of uncertainty in measurements Improvement of scientific reasoning
128	A	Being in labs- an opportunity we must use; teach –how to be scientist, think like scientist and prove your hypothesis; Can now see what is dependent and independent variable; learn how to control independent variable and take readings of dependent variable.	teach–how to be scientist, think like scientist and prove your hypothesis Understand how to work with different variables.
126	A	One of those who learn a lot; Get to know difference between variables and come up with	Understanding data of different variables

		solutions for particular problems; because of experiments- learned new stuff.	Learnt new stuff from experiments.
127	A	Learnt a lot from labs; Learnt ways of conducting and to write the experiment; last thing learned in labs is to be quick writer and thinker, since all practicals handed in before 17H00.	Able to perform an experiment Able to write up an experiment quick writing and thinking needed 17h00 report deadline
187	C	Sometimes learn sometimes don’t; going through prac before, watching YouTube videos and reading the book helps a bit; learn why we using certain values; Sometimes peer take you for granted- end up feeling down and losing track; working alone would be better.	watching YouTube videos before the practical helps Reading learning material helps Sometimes peer take you for granted—end up feeling down and loosing track learnt the use of some values Prefer individual work
156	B	The fact is labs change from trying to teach, to an activity where one has to obtain marks unconsciously aware that they losing objective of the experiment.	Lab work has become an activity for obtaining marks, thus defeats experiment objective
157	C	Although I do learn in labs, it’s very little in comparison to a lecture; Mostly learn uncertainties during labs.	Learn more in class than labs Learnt mostly about uncertainty
132	B	So far most learning done in classroom. In labs- learnt to interpret the theory learned in class in a scientifically methodical manner. There is not a lot of brand new information learnt apart from using the equipment.	Learn mostly in lectures than labs Less new information learnt apart from but the use of the equipment
175	A	Do learn a lot; because- you not only prove constants and learn to do better in your physics, helps you to work fast and effectively; learn to perfect graph work and report write-ups.	helps you to work fast and effectively Learn skills for plotting graphs Learn report writing skills
120	A	Learned a lot from labs; since most experiments were new; even learned there is lot I do not know	Learnt a lot in since most experiments were new

		or understand.	
118	A	Back at high school, when doing experiments—think of numbers; just numbers that will fit findings needed, not realising—sometimes results not that predictable.	High school didn’t equip to realize that sometimes results are not that predictable.
150	B	Most knowledge learnt in labs is already known from lectures	Most knowledge learnt in labs is already known from lectures.
106	A	Learned so much in labs; learnt more than what experiment requires, example, when doing pracs- also learn about factors that contribute to success or failure of method/desired results.	Learn beyond learning goals of experiments Understand factors that prevent successful experimental work
170	B	Nothing I can say I learnt because always lost. Didn’t get opportunity of learning in labs, because—don’t understand basics. It’s hard to learn.	Confusion Not able to learn as did not have prior “basics”
198	C	From the experiments I have done, they have been involving uncertainties. So uncertainties are the most things learnt from the labs.	Mainly learn about uncertainty analysis from experiments
173	B	Already know value of gravity of 9.8 m/s^2; did not need to know how we got there, so learnt nothing in terms–applying new work; have learnt things obviously, but nothing too interesting yet.	learnt nothing in terms applying new work Less interesting work learnt

From both tables it is noted that most of the respondents provided more than one reason for their FCR. No attempt was made to try to identify the dominant reason. Rather, all the Key Issues were established and used as the unit of analysis for coding the full data set.

4.1.1 Establishing reasoning categories from Key Issues

It is clear from Table 4-1 and Table 4-2 that many of the Key Issues indicated in the tables above can be regarded as variations of a similar theme. Thus, the next step was to identify and group such issues to form categories. One example of such categories is that the following Key Issues were grouped into a single category concerning "Time" (TM):

…Helps you to work fast and effectively, Quick writing and thinking needed, 17h00 report deadline, Stressful when time runs out and the work not complete, Not enough time to do experiment and write a lab report, Long lab session…

This process of identifying and grouping Key Issues as described was carried out separately for each of the Enjoyment and Learning probes. However, it is interesting to note that almost all the categories that emerged from the analysis of the Enjoyment probe also emerged in the analysis of the Learning probe. Only one category per probe turned out not be common with the other. Hence the grouping processes for the two probes are presented in a single table together in adjacent columns 1 and 2. Column 3 in Table 4-3 summarizes the categories that emerged from the Key Issues listed in columns 1 and 2 that were identified in the previous two tables

Table 4-3: Showing the grouped Key Issues of the Enjoyment and Learning probe with the corresponding reasoning categories.

Key Issues: Enjoyment	**Key Issues: Learning**	**Emergent Category (EC)**
• Stressful when time runs out and the work not complete • Not enough time to do experiment and write a lab report • Long lab session	• helps you to work fast and effectively • Quick writing and thinking needed • 17h00 report deadline	Time
• Technology exposure • Applying technology to lab work • Like Excel • Dislike Excel	• Watching YouTube videos before the practical helps	Technology Integration

• No lab experience is a disadvantage	• Successful experiments require prior knowledge • Not able to learn as did not have prior “basics” • High school didn’t equip to realize that sometimes results are not that predictable.	Basic Knowledge
• Experiments result in incorrect data which affects marks • Obtaining good marks compromises the fun in learning • Shift trying to understand the experiment to obtaining marks • Learn by doing more experiments at cost of marks	• Lab work has become an activity for obtaining marks, thus defeats experiment objective	Marks
• Report write up- unsatisfied about volume of work • report writing can be boring	• Able to write up an experiment • Learn Report writing skills	Report writing
• Uncertainty evaluations- unsatisfied about volume of work • Tedious and complicated uncertainty evaluations • Understand the need to report results but uncertainty aspect is very complicated	• Understand the concept of uncertainty in measurements • Learnt mostly about uncertainty • Mainly learn about uncertainty analysis from experiments	Uncertainty analysis
• Develop friendship from working in groups • Develop group interaction skills • Learn through group work • Group does not wait for me to understand • Enjoy practical with friends	• Sometimes peer take you for granted- end up feeling down and losing track • Prefer individual work	Student – Student relationship

• Nice “hands on” experience • Enjoy performing experiments • Not satisfied with 10% allocated to performing experiments • Not enough time to do experiment and write a lab report • Interesting to verify constant values by experiments • Performing experiments cultivates understanding • Long and challenging experiments • Enjoy practical part • Appreciate scientists and performing the experiments	• Learnt to understand procedures • Various experimental methods • Helps development Skill • Learnt new stuff from experiments. • Able to perform an experiment • Less new information learnt but the use of the equipment • Learnt a lot in labs since most experiments were new • Understand factors that prevent successful experimental work	Performing experiments
• Like Excel • Dislike Excel • nice knowing many ways of manipulating data • Data analysis- unsatisfied about volume of work • Tedious data analysis • Plotting graph very easy • Challenging calculations • Comprehend data analysis • Ability to manipulate data-in various ways is nice	• Learn skills for plotting graphs	Data analysis
• Encourages scientific thinking • Appreciate scientific thinking	• teach–how to be scientist, think like scientist and prove your hypothesis	Expert like knowledge

• Enjoys when the work is understandable • Helps understand the topic • Appreciate physics phenomena • Learn science and physics phenomena • Able to explain scientific concepts • Learning more things • Most of time don't understand • Performing experiments cultivates understanding • Understanding and explaining things better • Learn to apply existing knowledge	• Learnt various approaches to problem solving • Improvement of scientific reasoning • Understand how to work with different variables. • Understanding data of different variables • Learnt the use of some values • Representation skills • Learnt nothing in terms applying new work • Learn beyond learning goals of experiments • Less interesting work learnt • Learn more with unfamiliar concept	Understanding concepts
• Pre-practical question don't help • Unclear instructions • Lab manual-unhelpful • Experiments require more details	• Reading learning material helps	Instructional materials
•	• Learnt to do theory part practically • Illustrates work done in lectures • Learn more in class than labs • Most knowledge learnt in labs is already known from lectures. • Learn mostly in lectures than labs	Lecture and lab correlation
• Asking questions feels awkward • Calling demonstrators constantly makes one [me] look stupid		Student and demonstrator relationship

4.1.2 The coding scheme

Column 3 of Table 4-3 in the previous section lists 14 categories that emerged from the key issues shown in columns 1 and 2. These 14 categories thus served as the basis for coding the full dataset. The actual coding scheme comprises a two letter alphanumeric code that corresponds to each emergent category and is summarized alphabetically in Table 4.4. Note that for completeness and ease of reference, Table 4.4 also includes the code LR that emerged from the coding of the full dataset, as described in the section that follows. From this “fine-grained” coding scheme it is possible to identify cognate categories that could be grouped into larger categories. For example, one could conceive of combining Student-Student and Student-Demonstrator categories into a single Relationships category. However, doing the initial coding at a fine-grained level, apart from being somewhat easier to use, allows (a) for identifying and addressing specific practical issues, but more importantly (b) for forming larger categories using different perspectives. One way of combining the present categories will be discussed in Chapter 5.

Table 4-4: Coding scheme applied to data listed in alphabetical order together with new code LR that emerged from the full dataset (see text).

Code	Description
BK	Basic Knowledge
DA	Data Analysis
EK	Expert like Knowledge
IM	Instructional Materials
IT	Integration of Technology
LL	Lecture and Lab correlation
LR	Laboratory resources
MK	Marks
PX	Performing Experiments
RW	Report Writing
SD	Student-Demonstrator relationship
SS	Student-Student relationship
TM	Time
UA	Uncertainty Analysis
UC	Understanding Concepts

4.2 Application of the coding scheme to the full data set

The coding scheme shown in Table 4-4 was applied to the 100 full data sets of written responses of the Enjoyment (ENJ) and Learning (LRN) probes i.e. 200 FWR responses were coded. Each FWR was carefully read and coded for the Key Issue(s). Thus, each FWR led to one or more codes being assigned to the response. The codes were then entered onto a spreadsheet against the identifier (RIN) for the particular FWR. The coding was done with the proviso that it could be modified in the event that none of the codes described the response. The coding scheme turned out to be both robust and exhaustive in that it was only necessary to add one further category, namely Laboratory Resources (LR), to the original scheme (Table 4.4). It should also be noted that during this stage of the coding no attention was paid to whether or not the students expressed a like or a dislike for a particular issue. This issue will be discussed in the next section.

Appendix 4 captures the details resulting from the coding exercise as described. (Note that the P and N assignments that are also indicated there do not form part of the present exercise but will be discussed in section 4.3.) The full set of results as indicated in Appendix 4 are summarized in the form of frequencies per Emergent Category in Table 4-5, below. Row 1 of the table lists the codes while rows 2 and 3 are the frequencies for the ENJ and LRN, respectively. The table is arranged according to a decreasing frequency for the Enjoyment Probe.

Table 4-5: Table of frequencies of emergent categories identified in the Enjoyment and Learning probes with colour codes to indicate intensity of dominating category in terms of primary (red), secondary (green) and tertiary (blue) levels.

Category	UC	TM	PX	SS	IT	DA	EK	SD	RW	MK	IM	UA	LR	LL	BK	TOTAL
ENJ (no.)	32	29	24	22	13	12	10	10	9	9	9	8	5	2	1	195
LRN (no.)	36	16	42	8	12	6	8	3	8	3	4	15	5	11	8	186

To distinguish the relative importance visually the codes are grouped into red (> 20), green (10-20) and blue (<10) categories using the criteria. Owing to the fact that for each probes there are roughly a total of 200 issues, these categories correspond to >10%, 5-10% and <5%.

From the table it is clear that UC – Understanding Concepts, TM – Time, PX – Performing experiments and SS – Student-Student interactions are the main issues associated with the ENJ probe. These four categories account for about half of the issues that relate to the enjoyment of the lab. Interestingly, only two categories are dominant with regard to Learning but they correspond to two of the four for Enjoyment, namely UC and PX, which together account for over a third of the issues in this regard.

With regard to the ENJ results, IT, DA, EK, SD, RW, IM, MK and UA make up the secondary category while LR, LL and BK fall under the tertiary category. The corresponding categorization for the LRN probe are TM, SS, IT, EK, RW, UA, LL and BK (secondary) while DA, SD, IM, MK and LR are in the tertiary category. It can be argued that the reason for the so many categories being either of a secondary or tertiary level is that this categorization is an artefact of not grouping them into larger categories, but an important aspect that has a strong effect on the interpretation of the data is whether or not the issue identified was perceived to have a positive or negative impact. As an example, at this level of coding it would appear that grouping DA (data analysis) and UA (uncertainty analysis) would be a reasonable exercise to form a primary category in both instances (ENJ and LRN). However, as will be discussed later, this is in fact not entirely the case.

4.3 Coding for Perceived Positive or Negative Impact

4.3.1 Examples

As is noted above, while the coding scheme identified a number of key areas that had an impact on both students' Enjoyment and Learning, it is clear from the nature of the (original) written responses that the impact could be either negative or positive, and that this aspect was not captured in the coding described thus far. In this section, further analysis is carried out in which the responses are coded in terms of whether or not a particular response can be classified as having expressed an issue that could be regarded as having either impacted positively (P) or negatively (N) on the laboratory experience.

Some examples from the responses are shown below. In the first three cases that follow, the overall tenure is negative, as is each of the individual factors mentioned. Thus, each of these factors would be coded with an N.

- Enjoyment Probe RIN 187: FCR=B

[People around doing stuff new to me; they don't wait for me to catch up (N)]; [Pre-practical question don't help (N)]; [Don't enjoy at all, don't even ask question because is awkward (N)]; [calling demonstrators every time-look stupid (N)].

- Enjoyment Probe RIN 170: FCR=B

[Did not enjoy labs because of feeling lost (N)]; [Reading lab manual does not even help, always lost (N)]; [don't enjoy at all; always feel dumb in labs (N)].

- Learning Probe RIN 156: FCR=B

[Labs seemed interesting until learning [involves] marks, [then] shift trying to understand what experiment is about, to obtaining marks (N)]; [labs less fun and become a burden. Those who never used labs before are disadvantaged, even with tutors there to help, since basics of labs aren't taught (N)]; [learn by doing more experiments at cost of marks (N)].

The following three quoted responses show examples that are positive overall, and in which each individual factor would be coded P.

- Enjoyment Probe RIN 128: FCR=A

Enjoy labs, [because it's the real world of physics, see how things work (P)]; [teach interaction with other students (P)]; [listen and combine ideas to come up with solid conclusion, this helps think scientifically (P)].

- Enjoyment Probe RIN 127: FCR=A

Enjoyed being in the labs; [they are exciting since learn more things and gain knowledge (P)]; [Create friendship on group discussions (P)]; [get new ideas from students (P)].

- Learning Probe RIN 175: FCR=A

[Do learn a lot; because- you not only prove constants and learn to do better in your physics (P)]; [helps you to work fast and effectively (P)]; [learn to perfect graph work and report write-ups (P)].

4.3.2 Results from P/N coding

The impact coding exercise described above was completed for the full set of written responses for each of the Enjoyment and Learning probes. For most of the responses it was easy to identify the underlying sentiments conveyed by the respondent. The interrater reliability between my supervisor and myself was above 90 % and in each case the coding difference was easily resolved. The final data set coded in this way is shown in Appendix 8, and a summary in terms of frequencies per category is shown in Table 4.6 below. Column 1 shows the 15 codes used, while column 2 shows the meaning of the code. Columns 3 and 4 show the result of the coding for the ENJ probe when the response is also coded for Positive or Negative impact, respectively.

Table 4-6: Table showing a summary of the coded data, separated by P and N assignments.

Category	**Code**	**ENJ (P)**	**ENJ (N)**	**LRN (P)**	**LRN (N)**
Student-Student relationship	SS	15	7	6	2
Information Technology	IT	5	8	12	0
Understanding Concepts	UC	20	12	19	18
Lecture Lab correlation	LL	1	1	5	6
Student-Demonstrator relationship	SD	2	8	0	3
Performing Experiments	PX	15	9	32	10
Expert like Knowledge	EK	9	1	8	0
Basic Knowledge	BK	0	1	5	3
Time	TM	3	26	8	8
Uncertainty Analysis	UA	2	6	12	3
Data Analysis	DA	7	5	6	0
Instruction Materials	IM	0	9	1	3
Marks	MK	4	5	1	2
Report Writing	RW	1	8	5	3
Laboratory Resources	LR	4	1	4	1
	TOTAL	**88**	**107**	**124**	**62**

As can be seen in the table above, 88 of the responses that were provided indicated that the issue that affected the enjoyment of the lab did so in a positive manner. However, a larger number were associated with a negative impact. The corresponding results for the LRN probe are shown in columns 5 and 6. Here the trend is significantly reversed in that 124 reasons indicated a positive impact on learning and only 62 associated the issue that was raised with having a negative impact. The largest negative category related to the impact of time on the enjoyment of the lab.

At the positive end of the spectrum, the actual carrying of experiments (PX) was highly regarded in terms of learning. Interestingly, the PX category also featured highly as a positive factor in enjoyment of the labs. It is also interesting to note that the Understanding Concepts category featured positively at the same level for both ENJ (20) and LRN (19) probes. Curiously, however, the same factor had a negative impact on the LRN probe at almost the same level (18) while it was lower in terms of negative influence on enjoyment (12). It is possible that the negative influence of time was felt to be much more prominent in terms of a negative influence. As noted previously, Uncertainty Analysis (UA) and Data Analysis (DA) appear to be categories that can easily be combined. However, this was not done in case the P/N coding showed a clear distinction between the two. However, this is not the case, as the results are mixed and the numbers are small, so it would appear that combining them would not change anything from the perspective of interventions that might follow.

5. Discussion

The main aspects of the present study are summarized in the block diagram (Figure 5-1) below. To facilitate the discussion, each block is numbered in the lower right hand corner. Thus, block 1 shows the five main areas that were targeted in terms of probing students' views and perceptions of the first year laboratory engagement: (a) expectations, (b) enjoyment, (c) learning, (d) relationship between lectures and lab activities, and (e) relationship between experiments and theory. Blocks 2 and 3 detail that these areas were probed by means of a specially designed, written instrument, the Perceptions of Physics Labs (PPLQ), which consisted of five questions (Blocks 2, 3A and 3B). Each of the five questions was framed as a debate as indicated in Block 3B, and placed in the order shown below.

1. Expectations [EXP]
2. Enjoyment [ENJ]
3. Learning [LRN]
4. Relationship between Lectures and lab activities [LLR]
5. Relationship between Experiments and Theory [XTR]

As indicated at the bottom of block 3B, each question requested two types of responses: choosing a single letter (A, B or C), the "forced choice response" (FCR), followed by an explanatory written component, the "free writing response" (FWR).

The PPLQ was administered to a student cohort of 100 students from a first year physics course, as indicated in Block 4. The data that were produced were analyzed via the two parallel paths that are indicated. The left hand path shows the analysis of the FCR data for all five probes (Blocks 5 and 6) in which the choices of the respondents were tallied for each question. While the FWR data were available for each of the five probes, analyzing all the data went beyond the requirements of the present work. Thus, a limited set of data was chosen to be analyzed, on the following grounds: questions, EXP, LLR and XTR pertain to issues of *expectations and framing,* while the remaining two, ENJ and LRN, are reflective of *engagement as experienced*. Thus, the latter two probes were chosen for detailed FWR analysis. The FWR analysis of the ENJ and LRN probes is indicated by the right hand path, which details the steps that were carried out (Blocks 7-12).

As indicated in Block 7, the writing of the respondents was analyzed using a grounded approach (as suggested by Grounded Theory and Phenomenography, for example). Blocks 8 and 9 show some details of the exercise, in which a sample of 20 responses per probe was initially used to identify categories of reasoning. These categories were then used as the basis on which to code the full set of data. However, only one further category needed to be added to the original 14 categories during this exercise. Block 10 notes that results obtained in terms of the coding assignments were also presented as tabulated sets of coded data and frequencies of tallies per category.

While the process described identified key issues, the question of whether or not the identified issue was perceived to have a positive or negative impact did not form part of this part of the coding exercise. The positive-negative-impact (PNI) aspect was dealt with separately (Block 11). Block 12 shows the way in which the results from the additional PNI coding were finally summarized.

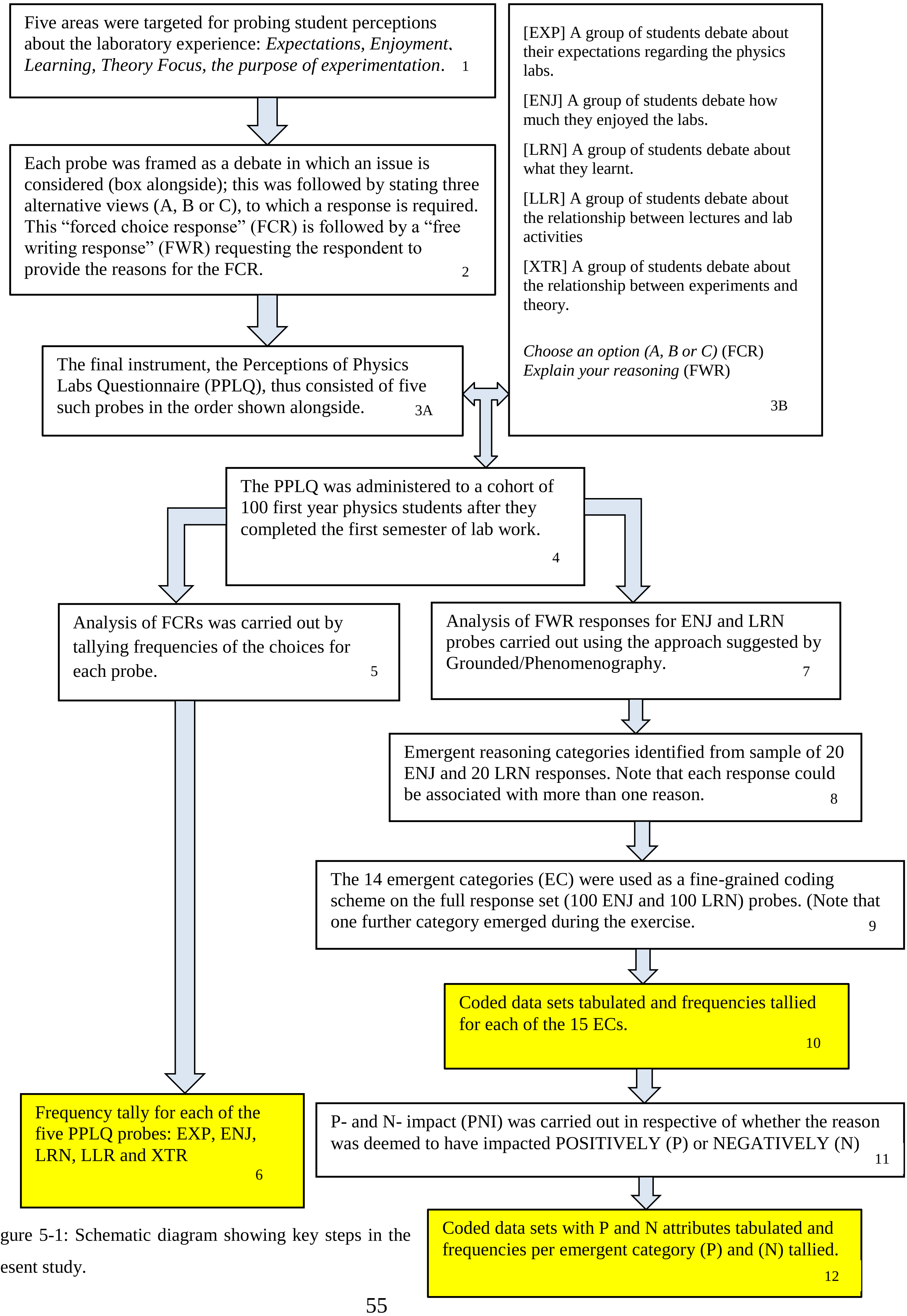

Figure 5-1: Schematic diagram showing key steps in the present study.

The discussion that follows in the remainder of the present chapter, is grouped into two main sections, based on the probes for which (a), only the FCRs were analyzed (blocks 6 and 7 in Figure 5-1) and (b), the probes for which both FCR and FWR analysis was carried out. The former group consist of questions EXP, LLR and XTR (Block 6) while the latter group consist of probes ENJ and LRN (Block 6 as well as Blocks 7 to 12). The first group is discussed in section 5.1 under the heading of "expectations and framing", while the second group is discussed in section 5.2 which covers aspects regarding the way in which the actual experience of engagement is perceived.

5.1 Expectations and Framing (EXP, LLR and XTR)

The quality of engagement that is brought to bear on a task depends on the cognitive resources that are activated at the time. In particular, the way in which the task is approached depends on the epistemological resources that are harnessed. In turn, whether a physics problem is seen as an answer-making exercise rather than a sense-making exercise depends on expectations and the way in which the task is framed. Thus, from the laboratory perspective, the way in which students engage both overall and with particular tasks will depend on their (a), expectations based on their previous experience with labs and/or their views about what happens in physics labs at university level and (b), the way in which they interpret the task at hand based on the way in which the task is presented as well as their views about the nature of experimentation. Thus, the EXP, LLR and XTR probes are connected to the actual engagement that follows.

It is recognized that, to fully link these probes to the ENJ and LRN probes, a student by student analysis needs to be carried out. However, the results of the EXP, LLR and XTR probes at the group level are informative from a broader expectations and framing perspective as detailed below. In order to facilitate the discussion, the results from chapter 3 are reproduced below.

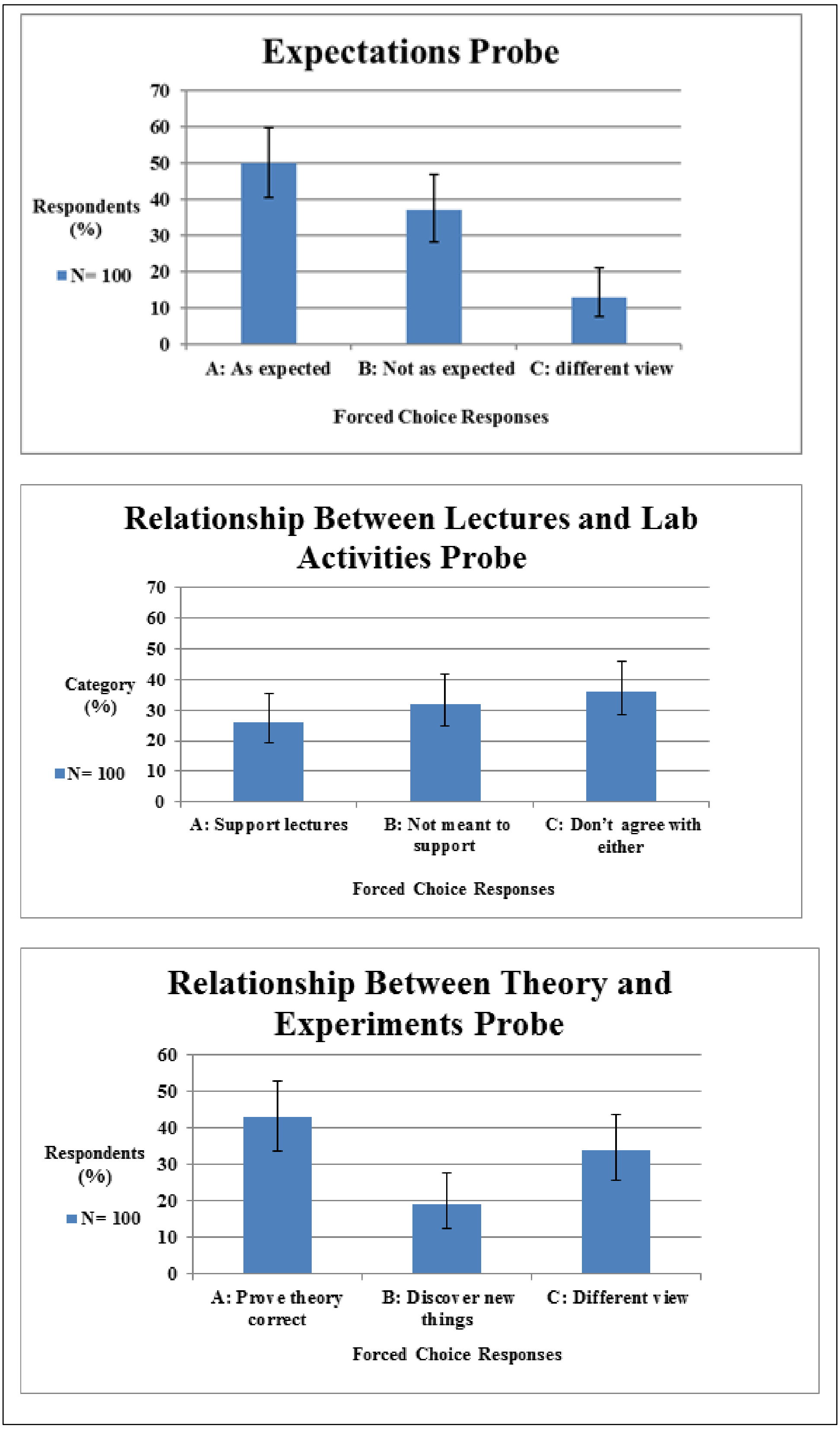

Figure 5-2: Results for EXP, LLR and XTR probes, as reproduced from chapter 3, showing tallies (y-axis) for forced choice responses A, B and C (x-axis).

While half of the students indicated that the labs had met their expectations (Figure 5-2; top panel, option A), about a third (37%) indicated that this was not the case (option B). A small group (option C) (13%) wished to express something other than simply align themselves with one of these views. However, whether or not this group is added to A or B, the overall finding remains the same, namely that a substantial portion of the class, at least a third, did not find the lab to be what they had expected. This misalignment between expectations and what happens in practice, could of course vary from the trivial to the serious. It is also possible that the detailed reasons for a large fraction of the students choosing option B might in fact turn to be of such a nature that the impact on the way in which they carried out the lab activities was not negative, but in fact positive i.e. that lab experience was above expectations and was in fact a satisfying experience relative to a poor school experience. However, the evidence from the Enjoyment probe (to be discussed in more detail, below) would appear to indicate that this would not likely be a majority experience.

On the other hand, while the relatively high proportion of students that chose option A might be viewed positively, in that having expectations aligned with what follows in practice helps in engaging productively, it is also possible that the reasons for choosing A might in fact not be desirable. For example, if the expectation of a lab is to follow a sequence of steps without deeper engagement, and this is what is borne out by the actual lab experience, the overall situation could not be regarded as positive. However, to gain further insight into the nature of the expectations and their relationship with the actual lab experience requires analysis of the FWR’s. What the present level of analysis shows, however, is that the issue of expectations is not adequately addressed in the way students are prepared for the overall lab course.

The last comment can also be made about the LLR question, which probes the perceived relationship between the lab and theory components of the course (i.e. three students are arguing about the lab versus the theory part of the course). While it is true that the lab manual handed to students in the beginning of the course states, *“While you will be able to reinforce, in the labs, some of the concepts you will have been told about in the lectures, the course is NOT designed with that goal in mind…”(Department of Physics/ University of Cape Town 2015)*, the results from the probe indicate that this statement by itself is not sufficient to frame the course and its activities. This can be shown by the fact that the perspective that is consistent with this view, option B (the labs were not meant to help with lectures or problem sets), was only chosen by about a third (32%) of the students. Somewhat disturbing is that a third of the students chose option A (I did not like the labs as they did not help us with lectures or problem sets), which is a strong dislike of the lab, based on an incorrect notion of what the lab course is stated to be about. It could also be argued that the students are expressing a desire that the lab activities *should* support the theory covered in lectures. However, these students could have chosen option C, the choice of about a third (38%) of the cohort, rather than by choosing the strongly negative option (A) in this regard.

Further analysis of the FWRs is required to establish the reasons for the choices as a number of interpretations of the data are possible. Amongst these are that some students might have chosen A in order to make a very strong point about the fact that they would have liked the labs to have helped with the theory. Similarly, option C might have been a statement of not liking labs at all, whether or not they related to the lectures. At worst, both A and C could be proxies for students who consider the lectures to be covering the “real physics” and that, should the lab not support this, they are a waste of their time. The view that lectures are much more important than labs is often reinforced by the fact that the lab activities are not assessed in the same prominent way as lecture-based theory. From the perspective of running the lab course, it is clear that attention needs to be paid to how students perceive the purpose of the lab relative to the theory, as incorrect framing will clearly have a negative impact on activity engagement and thereby on the pedagogical outcomes.

The third probe (XTR) was aimed at probing student understanding about the broad purpose of experiments in physics (as a scientific enterprise). However, it is possible that the four questions that preceded this one, which were about first year labs, might have led some students to answering the question as though it pertained to their experiences of carrying out experiments in the first year lab. Whichever way the question was interpreted, it is still striking that almost half of the respondents (44%) chose option A, namely, that the main aim of experiments in physics is to prove the theory correct. Whether or not the question was interpreted to refer to the local situation of the first year lab, or whether it was seen to refer to physics more broadly, the same conclusion appears to follow insofar as the framing of experiments is concerned, namely, that experiments play a secondary role to theory in physics.

Thus, if the overall enterprise of physics relegates experiment to this level, it is not far-fetched to assume that students who hold this view are just as likely to hold a similar view with regard to carrying out experiments in the first year lab. In turn, such a perspective would appear to be more naturally consistent with priming answer-making epistemological resources rather than with exercising sense-making and critical thinking. Furthermore, it seems likely that, if the probe were rephrased to make the question relate to the first year lab, more respondents would have chosen A. Thus, the present percentage of students who chose A can be interpreted as a lower limit for a question pertaining specifically to first year labs.

Unlike the difficulties in understanding how the "option A" students might have interpreted the question, it is more likely that the roughly one fifth of the students (19%) who chose option B (discover new things) had the broader enterprise of physics in mind, as it would seem unlikely, given their experiences of the labs described in section 1.7, that they would agree that something new would be discovered in the first year physics lab. Without a detailed analysis of the FWRs, it is not possible to get an idea of what the range or preponderance of views of the 34% who chose option C might be.

Taken together, the results of the FCR analysis of the three probes in question indicate that the cohort of students frame the first year lab in a variety of different ways, a large fraction of which would appear to lead to problems when engaging with lab activities that are meant to foreground experimentation. While aligning expectations with what actually takes place in the lab can be addressed explicitly by a carefully planned introductory set of activities, the issue of framing, however, is not as straightforward. It is clear that simply stating upfront what the course is about, or even emphasizing what it is not about, does not work, as indicated from the discussion above. While spending more time on making sure that students have a much better picture of what they are going to be doing and how it fits into their overall physics course is, clearly, likely to be of value, it is the nature of the activities that make up the course, and the accompanying meta-messages, that will speak most strongly to framing. Thus, whatever the intention of the course may be, the way each activity is framed will (1) send a meta-message about the role of experimentation in relation to theory and (2), weight the epistemological resources toward either answer-making or sense-making. An examination of the actual lab activities (section 1.7, 1.7.1 and appendix 2) shows that these are very much framed in a traditional style, despite the addition of a few innovations. Thus, the contents page of the manual (see appendix 2) highlights physics topics such as free fall, the simple pendulum etc. as opposed to say a list of skills such as graphing or using an Excel spreadsheet. Each lab is then structured in a way that appears to foreground a skill such as tabulating, graphing etc. However, following the statement that declares what the skill is, the way in which the lab is structured then follows a more traditional approach in which some theory is highlighted and the skill then appears to be secondary, or in the service of the "real" aim. To take the first 2 labs in the guide as examples,

Lab 1:

Hooke's Law: Determining a spring constant

The deliverable for this practical is a full write-up to be handed in by 5:00 pm on the day of the practical.

In this practical the emphasis is on structuring the report, tabulating readings and drawing graphs.

Read through section 4 of the Laboratory Guide to Reporting and Measurement.

In this first practical there is no need to perform uncertainty evaluation, but you should be aware of what is meant by the uncertainty in a measurement.

Aim: The aim of this experiment is to investigate the relationship between extension of a spiral spring and the magnitude of the applied force causing the extension, and from this relationship, to determine the spring constant.

Lab 2:

Simple Pendulum

The deliverable of this practical is a full write-up to be handed in by 5:00 pm on the day of the practical.

In this practical the emphasis is on using EXCEL to do calculations, to plot a graph, and to perform a type A evaluation of uncertainty.

Aim: The aim of this practical is to investigate the relationship between the length of a simple pendulum and its period of oscillation; and from this relationship, to determine the gravitational acceleration g.

In each case the preamble suggests that skills are to be the focus then goes on to strongly suggest (sending the meta-message) that the lab is in fact about a specific theoretical aspect. The second issue, then, is that the tone of each of the labs is that of the voice of authority and little is left to the student but to follow the instructions in order to get to the expected outputs. While it likely that the intention of the labs is indeed to use the physics theory as a vehicle for teaching the skills, the way in which it is presented makes it appear as if the skills are being used in the service of demonstrating some theory or measuring a well-known constant. Thus, the overall approach, which has much in common with the cookbook approach, is more likely to activate answer-making epistemological resources than sense-making resources.

The result of the way in which the present expectations and framing play themselves out in the engagement phase of the lab is discussed by a closer look at the two probes that deal with perceptions of enjoyment and learning. For these probes both the FCR and FWR data were analyzed as has been noted earlier.

5.2 Laboratory engagement as experienced (ENJ and LRN)

In order to facilitate comparison, the individual results of the FCR data that were presented in section 3.1 are shown together on the same graph below. The data are grouped into three, where the first pairing consists of strongly positive sentiments, for both Enjoyment and Learning, while Group 2 pairs the strongly negative responses.

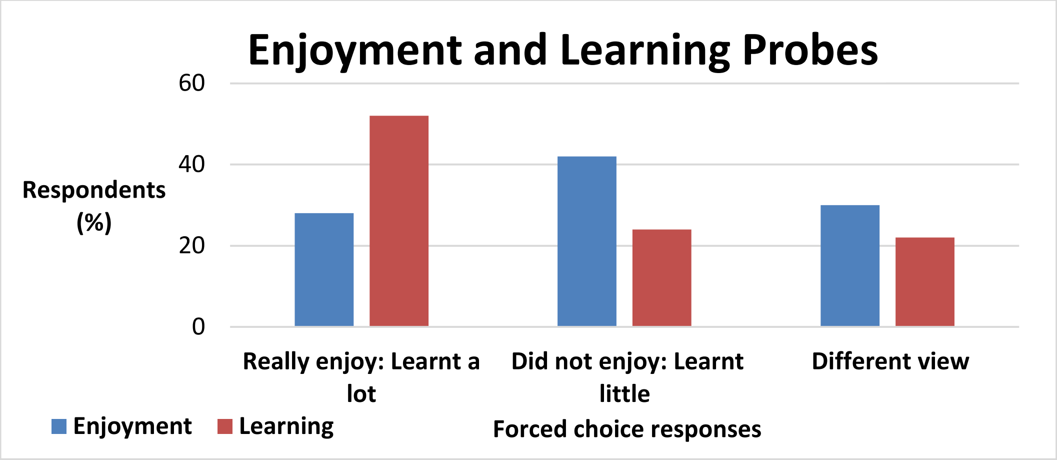

Figure 5-3: The figure shows the frequency distribution of the FCR data for the learning and enjoyment probe. The results are paired into three groups where the first group shows positive perceptions for enjoyment and learning and the second group shows the negative sentiments.

The most striking feature when the two sets of results are placed alongside each other as shown is that the experience of Enjoyment and the perception of Learning are not commensurate with each other. Thus, while more than half of the cohort felt that they had learnt a lot in the lab, just over a quarter considered the lab to have been an enjoyable experience. While only about a quarter of the cohort felt that they had learnt little, this is not an insignificant proportion. It is reasonable to speculate that the last group held views consistent with "something was learnt" and that the lab experience was "tolerable". Thus, if we add the results from Group 3 to the first group, then overall it can be said that the majority of students (roughly 70%) appear to indicate that there had been some form of learning gain in the lab. On the other hand, the fact that more than 40% of the cohort felt strongly enough to choose what is an extremely negative option for the enjoyment probe, (rather than the "different view") is disturbing. However, the range of reasons as to why the labs might be perceived in such a strong negative way can vary widely.

The reasons that underlie the pattern of FCR results were investigated by analyzing the explanatory written responses of the students by coding the FWR data, as detailed in previous chapter, and summarized in table form after coding for Positive or Negative impact. The tabulated results are presented below in graphical form to accompany the discussion for the reasoning categories. In each graph the horizontal axis shows the coding categories. Each category is associated with two histograms, the left bar of each pair indicating the results of Positive (P) impact coding while the right bar shows Negative (N).

The first graph below shows the distribution of responses for the ENJ probe while the second graph shows the distribution for the LRN probe.

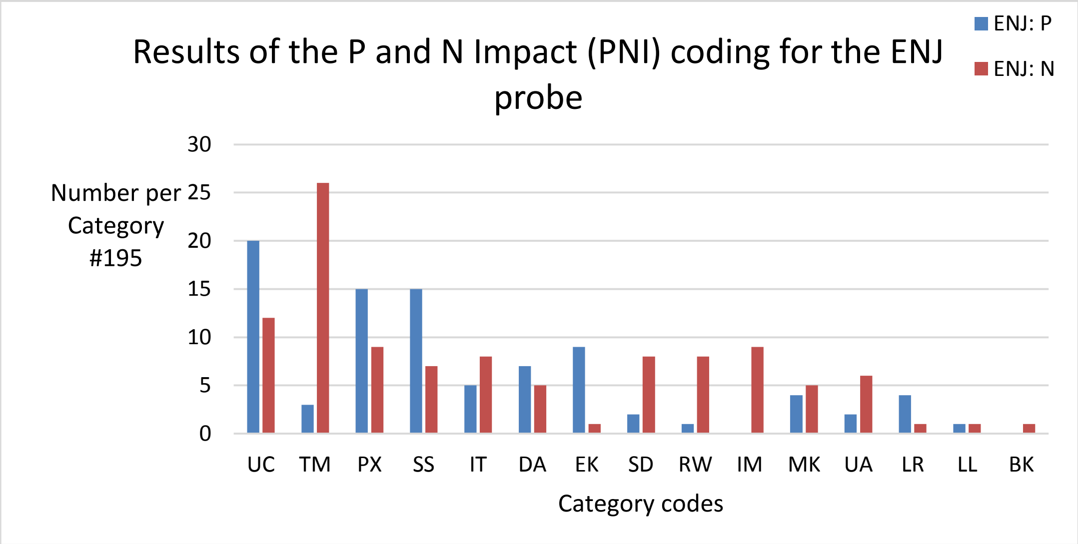

Figure 5-4: The figure showing the frequency of Positive (P) and Negative (N) impact codes that exist in the Enjoyment (ENJ) free writing responses for the full data set.

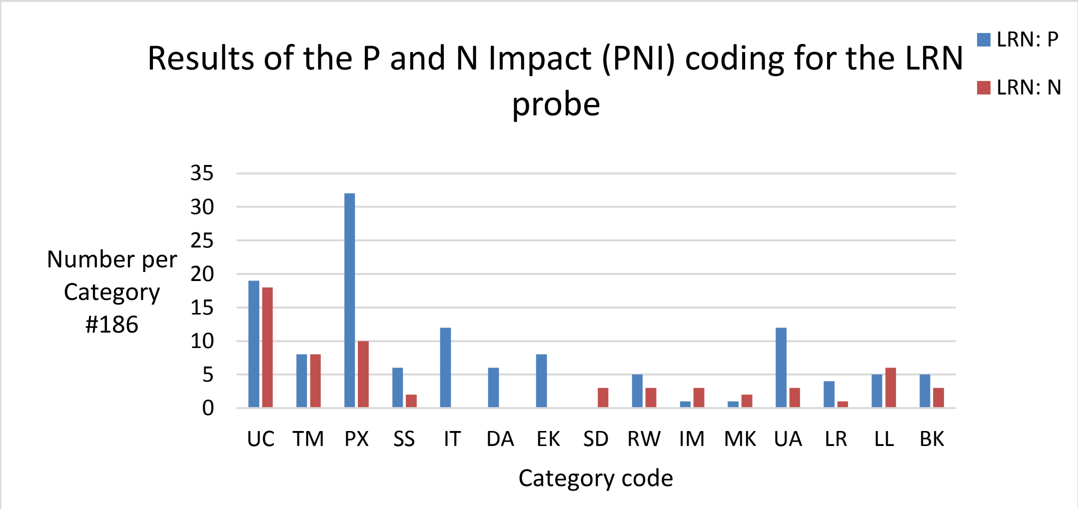

Figure 5-5: The figure showing the frequency of Positive (P) and Negative (N) impact coding that exist in the Learning (LRN) free writing responses for the full data set.

It is clear from both sets of results that there are indeed aspects of the lab that can be regarded as positive. This is an important finding, as it shows that students perceive learning benefits from being in the lab, despite the fact that certain aspects are clearly found to be negative. While it can be argued that this finding is already contained in the FCR data, it is important for the study as a whole to be able to identify what the actual factors are that result in the FCR data. It is also informative from the perspective of the instrument that was used, that the students did not simply select choices at random but that the nature of the responses indicates that they were in fact engaging with the questions in a meaningful manner. While it is encouraging that there are positive, identifiable aspects to the lab, it is clearly of importance to understand the nature of the negatively expressed aspects.

Part of understanding the laboratory environment and students' experiences using the results of the data used in the present study is the main thrust to questions pertaining to the negative and positive impacts. When analyzing the P and N impacts presented in the previous chapter a few observations were noted regarding the frequencies of the categories that had high P's and N's. In this discussion, we quote several statistics from the two graphs above, which represent the results in the preceding chapter, to point out key observations. It is clear from Figure 5-4 that Time (TM) is the main reasons why the lab is not enjoyable. However, it is not clear what "Time" is a proxy for, as a time cutoff could impinge on many of the other issues that are listed. As noted earlier it would also not seem very likely that the issue of time in itself would generate the strong negative levels that are shown in the FCR data. At the level of simplicity, thus, it is not clear that just allowing the lab times to be longer would reduce the negative responses.

Other than Time, there is no other single factor that that can be identified as a key cause for not enjoying the lab, as all the N (red) bars are spread across the graph and each N (red) bar either is not a significantly large number or does not appear to be significantly different from any other. On the Positive side P (blue), Understanding Concepts (UC), Performing Experiments (PX) and Student-Student relationships (SS) stand out as identifiable reasons for enjoying the lab. It is interesting to note that SS is a social factor.

With regard to the LRN results (Figure 5-5), the factor that stands out most clearly is Performing Experiments (PX), and this in fact is a Positive P (blue) factor. Three other positive factors that stand out to some degree are UC, IT and UA. All four factors are related to the actual lab task itself. It is interesting to note however, that while UC is the second most important Positive factor it is also identified as the most Negative factor in terms of learning in the lab.

5.2.1 Intrinsic and Extrinsic groupings

From the two sets of data (ENJ and LRN), one way that suggests itself to group the factors appears to be that they are of two types: those that are “Intrinsic” to the lab task engagement and others that can be regarded as “Extrinsic” to the task engagement such as Time (TM) and Social aspects (SS and SD).

The following can be argued to be Intrinsic: Understanding Concepts (UC), Performing experiments (PE), Expert like Knowledge (EK), Basic Knowledge (BK), Data Analysis (DA), Integrating Technology (IT), Report Writing (RW), and Uncertainty Analysis. The remaining ones are Extrinsic: Students-Student relationships (SS), Students-Demonstrator relationship (SD), Marks (MK), Time (T), Lecture and Lab work correlation (LL), Instruction Materials (IM) and Laboratory Resources (LR). In the cases of both Marks and of Time, the rationale for categorizing them as Extrinsic rather than Intrinsic is that the comments pertaining to these issues are strongly suggestive of them being viewed as systemic boundaries. Thus, while it could be argued that marks are a consequence of the effort put in by the students, the system of marks is not set by the students, nor can the mark be changed afterwards as it is a largely summative form of assessment in the way it is applied in the lab. Similarly, with Time, while it could be argued that completing the lab tasks depends on the speed with which students proceed, the actual issue is that the allotted time is fixed and, as can be seen by the relevant quotes, is a major obstacle in engaging with the lab.

Table 5-1 shows the previously identified categories listed into two groups, Extrinsic Factors and Intrinsic Factors. Under the two groups are three columns, the first is a list of descriptions of all categories assigned to the group (Intrinsic and Extrinsic) followed by a column of the code separating the Positive and Negative impacts identifiers. The third column shows frequencies for the assigned categories.

Table 5-1: Previously assigned categories placed into two larger groups, namely Extrinsic and Intrinsic, as described in the text.

Extrinsic			**Intrinsic**		
Category	**Code**	**Count**	**Category**	**Code**	**Count**
Student-Student relationship	SSP	21	Uncertainty Analysis	UAP	14
	SSN	9		UAN	9
Student-Demonstrator relationship	SDP	2	Data Analysis	DAP	13
	SDN	11		DAN	5
Marks	MKP	5	Integrating Technology	ITP	17
	MKN	7		ITN	8
Time	TMP	11	Understanding Concepts	UCP	39
	TMN	34		UCN	30
Instructional Materials	IMP	1	Expert like Knowledge	EKP	17
	IMN	12		EKN	1
Lecture-Lab Correlation	LLP	6	Report Writing	RWP	6
	LLN	7		RWN	11
Lab Resources	LRP	8	Performing Experiments	PXP	47
	LRN	2		PXN	19
			Basic Knowledge	BKP	5
				BKN	4

Table 5.2 below shows the results of combining the frequency data for the categories shown in Table 5.1 into the larger extrinsic and intrinsic groups for each of the Enjoyment and Learning probes. For the purposes of clarity, the details are included below.

Table 5-2: Results from fine-grained coding grouped into two main groups in terms of factors “intrinsic” and “extrinsic” to the lab task engagement. Note that all the values in the brackets written in italics are percentages of all reasons in the learning and enjoyment separately and those in bold are as per all the **381** reasons evoked in the responses.

Probe	Extrinsic			Intrinsic		
	Positive	*Negative*	**Total**	*Positive*	*Negative*	**Total**
Learning (LRN)	25 *[50]*	25 *[50]*	50 *[100]*	99 *[73]*	37 *[27]*	136 *[100]*
Enjoyment (ENJ)	29 *[34]*	57 *[66]*	86 *[100]*	59 *[54]*	50 *[46]*	109 *[100]*
Total	54 **[**_40_**,14]**	82 **[**_60_**,21]**	136 **[**_100_**,36]**	158 **[**_64_**,40]**	87 **[**_36_**,23]**	245 **[**_100_**,64]**

From the table it can be seen that while the total number of “Intrinsic” reasons invoked [245] is about twice that of the number of “Extrinsic” reasons [136], the “Extrinsic” group is substantial, comprising 36% of the total reasons invoked [136/381=36%]. It is also striking that two thirds of the Intrinsic reasons are in fact Positive [158/245=64%] and that only a third of the reasons [87/245=36%] are indeed perceived to have a negative impact on the lab engagement experience. In contrast, 60% [82/136] of the “Extrinsic” group are perceived as factors that impact negatively on lab engagement.

5.2.2 Emotional aspect of the lab

While the instrument that was used identified a large number of apparently very different issues, grouping them into the two groups intrinsic and extrinsic as in Table 5.2 appears to point the way to how to promote better lab engagement. The factors that are identified as intrinsic are relatively easy to deal with, as they involved specific issues relating to skills and concepts. However, the extrinsic factors are somewhat more complex as they relate to the broader environment. This includes social interactions as well as other systemic issues (marks system which appears to some students to be punitive, time strictures) and structural issues (lab resources, instructional materials and lecture-lab correlation). However, it should also be pointed out that the lecture-lab correlation could also be regarded as an issue pertaining to the framing of the individual lab tasks, the meta message of which is at odds with the explicitly stated purpose.

We suggest that the two groups, intrinsic and extrinsic, can also be seen from the perspective of locus of control. It is interesting that the intrinsic factors are such that a student can in fact do something about it and in that sense the issue is under their control, *internal locus of control*. On the other hand, the extrinsic issues are such that a student does not have direct control of the issues, *external locus of control*. Thus, for example, it is beyond the locus of control of students to control either the social situation, the grading scheme or the allotted time. Hitting up against these issues thus makes one feel powerless and leads to frustration, which is the source of the negative emotional expressions. This can be evidenced from the following quotes below that relate to some of the categories that at first sight do not necessarily appear to be of an emotional nature in themselves.

Category: Marks (Each quote may have more than one reasoning category)

I love physics but the group that I work with makes me not enjoy practicals as my opinions are mostly excluded and I sometimes don't understand what's happening and get frustrated as the tutors are sometimes useless and end up getting low marks for pracs even the experiments are dull.

At first, labs seemed interesting until learning has marks, shift trying to understand what experiment is about, and to obtaining marks; labs less fun and become a burden. Those who never used labs before are disadvantaged, even with tutors there to help, since basics of labs aren't taught; learn by doing more experiments at cost of marks.

Reason-Labs change from trying to teach, to an activity to obtain marks unconsciously aware that they losing objective of experiment.

Labs do not fulfill my expectations, because I expected to do something practical and walk out understanding the purpose behind the practical. But for me what happens is the total opposite. I always walkout more confused, I get good marks but I do not understand the practicals.

There is very little learning for me in the lab, I would rather understand the purpose of doing the practical, but I feel that it is not so, that we in it for the marks. I always manage to walk out of the lab clueless.

Some things done in labs were not even mentioned in lectures; felt like we just doing them for sake of lab sessions and marks

It is interesting to see that even where the marks are good the student feels unfulfilled.

Category: Time

More than anything, it is the timing of the lab sessions and how much they drag out through the afternoon. Students' attention span (especially after a day of lectures) is usually worse than ever. It would be wrong to say that the lab practical are not fun but more that the fun is drained from the lab practical. Science is our major, finding out conclusions and results is our calling but lab practical kills it sometimes.

I enjoyed the labs because: - interaction with fellow students, - new skills gained due to new equipment's being used, and new knowledge gained (i.e. uncertainty). I did not enjoy the labs because: - they take so long, tired and frustrated after so long, - we are required to hand in a full report on the day the practical is done, - we don't/haven't done anything new/interesting (covered gravity experiments in...)

Sometimes, I enjoy them but most of the time I leave feeling frustrated, and with no understanding of what I just did

Usually during the pracs I am tired and my concentration is severely lacking. What I learn is in the moment usually forgotten by the time I leave the lab and rarely do I ever think back and utilize what I saw/learnt from the lab session.

This emotional theme can in fact also be seen in many of the responses that refer to social relationships. A few examples showing expressions of positive sentiments are shown, while the remaining ones show how poor social interaction leads to feeling of negativity toward the lab.

Categories: Student-Student relationship and Student-Demonstrator relationship

The following are positive examples,

The lab sessions provide the opportunity to work with other fellow students. Where everyone has their own ideas; when those ideas are combined then a well thought of lab session can be represented.

Yes, Sometimes I enjoy the labs as it helps us as students to work together and interact with one another.

Enjoyed labs; excite since, learn more things; Create friendship on discussion as groups; get new ideas from students.

A lot of work-its University after all; Just not enough clarity gathered from manual, many students- come in and see what other students planning before conducting experiments, don't have exposure to Excel/linear fit-manual doesn't thoroughly explain, which looks like a disadvantage.

The following are negative examples,

So far I cannot say I enjoyed the labs as I get to encounter a lot of challenges. My situation has turned out to be that of feeling a bit oppressed and undermined by fellow students. It came to a point where in you fear to speak your mind out or talk confidently. Also I have a problem with work that requires computations as I type slow and not really familiar with excel.

I do not really enjoy the labs, because most of the time I don't get to interact with others, even though there is interaction in groups of three, I feel like it's just like a race against time to get whatever practical done and not actually learn from doing the practical.

Stressful, nerve wrecking, very few demonstrators actually know what is going on, instructions are never clear often confusing. Never enough demonstrators to go around, so you have to wait for long. I generally don't enjoy physics.

People around doing stuff new to me; they don't wait for me to catch up; Pre-practical question Don't help; Don't enjoy at all; don't even ask question because is awkward; calling demonstrators every time-look stupid.

5.3 Towards understanding lab engagement

It is clear from the preceding discussion that an understanding of what happens in the lab does not only depend on purely cognitive issues but also on affective aspects. One of the reasons for this is that unlike problem solving in physics (i.e. back of the chapter types of problems) which can easily be reduced to a series of steps in a somewhat artificial environment, negotiating the lab space is much more complex. In this section, we discuss these issues in terms of (a) framing, linked with the FCR, and (b) the cognitive-emotional link. In attempting to understand the engagements in the first year laboratory environment, the two aspects are viewed collectively through The Idea Space Model of Allie & Demaree (2010)

5.3.1 Framing

The term "framing" is used in the same sense as introduced by Goffman (1986), and more specifically in PER via the work of Hammer et al. (n.d.) as "the unconscious answer to what it is that's going on here". It should be noted that "what is going on here" is a process that takes place on a milliseconds time scale. We have noted that some parts of the results can be regarded as aspects that form the framing in the lab. Therefore, students' sense making of the lab task is revealed in the study in two parts: (1) the positive and negative impacts of aspects of the students' external locus of control and (2) the probes 1 (XPT), 4 (LLR) and 5 (XTR). These inform us of students' perceptions of the lab. (However, the latter aspect is not explored intensely as it would require a grounded student by student analysis of the FWR data, which was beyond the scope of the thesis unlike the former). With regard to the FRC results of this study, expectations explored in probe 1 and interpretation of the purpose of the labs elicited in probes 4 and 5 are what forms the basis of framing in the context of the present work.

The manner in which students engage with the lab task can be modelled as being determined by the cognitive resources primed. One of the factors upon which different resources are primed is framing. Hence it is noteworthy to mention the link that the analysis of the probe has towards students' framing of the lab task.

We further demonstrate that the way students interpret the task is highly dependent on the manner in which the task is presented. The quality of engagement (with lab task) is dependent on what we refer to as sparse or rich network of resources – those primed. In essence the manner in which a student engages with the task will differ accordingly. This idea is demonstrated in the following example showing how asking questions in different ways can elicit different responses:

"Will air resistance affect the motion of the object?" as opposed to the question "Make a list of all the possible factors that you consider could affect the motion of the object and next to each write down if you think it will have a large or small effect." The former question puts a student in the frame of recalling authoritative information and being either correct or incorrect with only two possible choices: yes or no. [see appendix 9]

If useful and appropriate resources are primed for potential use, the students will can utilize them when engaging with the lab activities, thus a higher quality of engagement comes about.

Students' expectations, especially for first year labs, are influenced by their various positionalities (i.e. prior school experience, general engagements with the scientific community etc.). Other noteworthy influences come about the introduction of the lab course (by means of manuals, introductory talk by the convener and what they see when they enter the lab space to mention a few). These expectations and influences will form part of the basis of students' interpretation of the purpose of the lab course. While the interpretation in this regard is dependent on students' understanding of the role of experiments and theory in physics, the implementation of purpose of the lab enterprise itself conveyed to students is important. The lab convener is mostly influential because of their responsibility of developing and presenting the lab exercises – how the lab is to be framed by the students. For example, the experiment procedure in the manual can cause students to frame the activity as sense making or answer making (see studies by Allie et Al., Sharma and Holmes and Gresser, where they did away with traditional procedures in their respective courses). Thus, it is important that clarity of purpose of the lab is established in the beginning of the course to avoid interpretations that are at odd with the purpose of the lab.

From the above views, we have demonstrated that students' expectations influence how they interpret the purpose of the lab and hence will determine too how they engage with the task at hand. Expectations play a major role in how students interpret various aspects of the lab. For example, if the students' expectations regarding the purpose of experiments is to prove the theory correct in an experiment that involves the "calculation of the acceleration due to gravity”, when the main purpose of the lab is to learn how to deal with uncertainty of a measurement, the students might be highly cognitively occupied with determining the closest value to the “true” value of g. This can be problematic because of the possibility of losing the focus of goal of the lab, a missed opportunity for a more meaningful engagement that would foster scientific thinking skills as intended by the lab convener.

Questions EXP, LLR and XTR all probe students’ aspects of framing of the labs. Question XTR probes students’ interpretation of the purpose of labs with respect to either a global or localized perspective. On the other hand, question LLR deals explicitly with localized issues on expectations and the purpose of labs. It is clear that at this level there needs to be an alignment between students’ engagement in the lab and the manner in which the experiments are carried out as stipulated by the convener. The PPLQ questions on Framing are context dependent and this should be considered when administering the questionnaire for future investigations.

5.3.2 The cognitive emotional link

When engaging with a lab task in an environment set up for first year teaching, not only do the physics concepts and tools come into play, but several decisions of a real-world type have to be made during experiments, while at the same time social aspects also have to be negotiated. Thus, the processes that are brought to bear on the issues are not only cognitive but rooted in the emotional aspects of engaging, as is clear from the preceding sections of the study.

Figure 5-6 reproduced from the Immordino-Yang & Damasio (2011) paper shows the deep link at a neurobiological level between cognition and emotion.

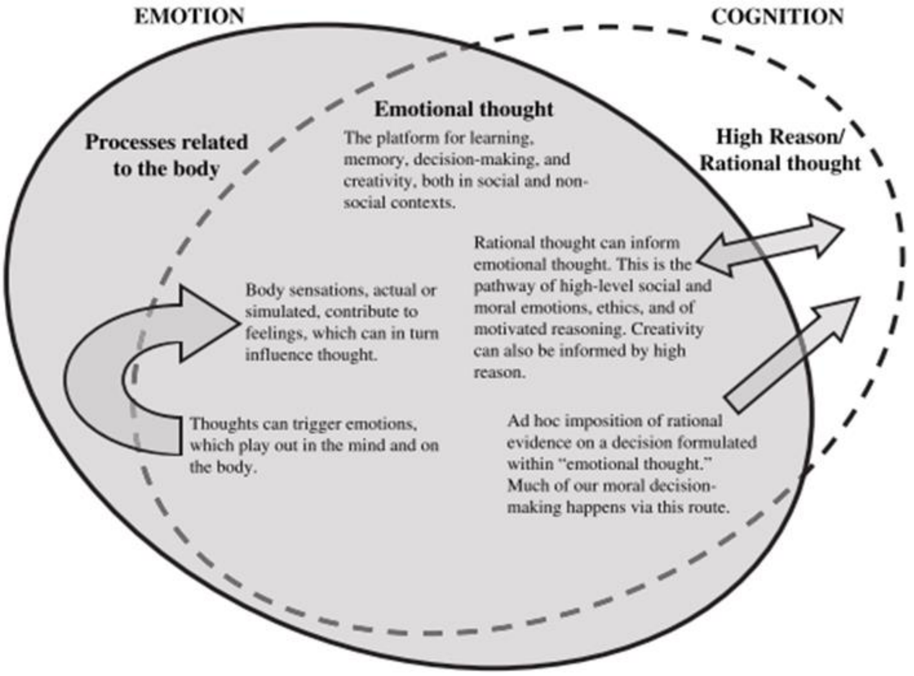

Figure 5-6: The cognition-emotional model as reproduced from Immordino-Yang & Damasio (2011).

In their paper, Damasio and Yang summarize the link between cognition and emotion in the caption that accompanies the above diagram as follows: "The evolutionary shadow cast by emotion over cognition influences the modern mind. In the diagram, the solid ellipse represents emotion; the dashed ellipse represents cognition. The extensive overlap between the two ellipses represents the domain of emotional thought. Emotional thought can be conscious or nonconscious and is the means by which bodily sensations come into our consciousness awareness. High reason is a small section of the diagram and requires consciousness".

As stated in the diagram "Emotional Thought (is) The platform for learning, memory, (and) decision making…" Yang and Damasio emphasize in the text "the aspects of cognition that are recruited most heavily in education including learning, attention, memory, decision making, motivation and social functioning are profoundly affected by emotion and in fact subsumed within the process of emotion". All these aspects pertain to the lab as can be seen from the data: expectations, framing, social interactions and self-esteem. However, the impact on the quality of student engagement given a particular emotional state is not part of the present work but would appear to be an important aspect to investigate. If the link between cognition, learning and emotion is as strong as it is made out to be then the evidence from the present study is troubling, if only for the fact that the ENJ probe points to strong negative emotions at play that could be undermining much of the possible learning that could actually be taking place.

5.3.3 The Idea Space Model

With regard to the lab itself, the question arises as to how to address the issues that have been raised above in a holistic manner that will promote high quality engagement. Taking all the cognitive and affective aspects into account when structuring physics tasks is not easy. To this end, Allie & Demaree (2010) have developed the "Idea Space Model" that links the issues discussed to task development. In their paper "Toward Meaning and Scientific Thinking in the Traditional Freshman Laboratory: Opening the Idea Space", Allie & Demaree (2010) explore the issues pertaining to "backstage cognition" including both framing and affect that impact on the quality of engagement. A more recent presentation at the World Conference of Physics Education-WCPE details the Idea Space in greater depth (see Appendix 9). Key to the model, using a geometrical metaphor, is that the "size of the Idea Space" is linked to the quality of engagement. Thus, a small Idea Space leads to poor engagement while a large Idea Space promotes quality engagement. In turn, the size of the Idea Space depends on a number of factors ranging from the conceptual metaphors that are used as footholds in order to engage with the task at hand, to socio-cultural factors that either promote or limit the quality of engagement.

As a simple illustration: The Idea Space is affected by the manner in which a question is put to students. So for example, posing the question, 'Will air resistance affect the motion of the object?' leads to a small Idea Space, while requesting the student to "Make a list of all possible factors that you consider would affect the motion of the object and next to each write down if you think it would have a large or small effect" leads to a larger Idea Space. One important factor that is discussed is the notion of monitoring (the situation at hand) that compromises the Idea Space. It is interesting to note that an observational study (in a first year engineering physics class) of instructor moves relative to the ensuing "quality of engagement" showed that the quality of engagement was well predicted by the Idea Space Model. (Jennifer Roth, "Small Group Discussions in Large Lecture: Connections between Teacher Facilitation and Student Participation", December 2011 Unpublished M.Sc. Thesis –University of Oregon) (Roth 2011).

5.4 Summary and Conclusion

The present work reports on a pilot study that forms part of a larger project regarding the first year laboratory at the University of Cape Town physics department. The main steps of the present work can be summarized as follows.

A written instrument for probing student perceptions of the first year lab was developed and piloted. The instrument, the Perceptions of Physics Lab Questionnaire (PPLQ), elicited two types of responses: (a) forced choices and (b) free response writing. The instrument was piloted by administering it to 100 first year students enrolled in an introductory physics course.

A framework for analysis was developed and used for analyzing (a) all the FCR data and (b) two of the free writing responses using a grounded approach. The results from the pilot exercise indicated that the instrument was robust and that only a few changes would be required in future applications. While a detailed analysis of the question is not part of the present work, it was clear from a quick reading of the free writing responses that the wording of question 5, regarding the relationship between theory and experiments, could be interpreted in two ways. Thus, the question might need to be revised depending on the intended area to be probed.[2]

The analysis of the two sets of free writing responses indicated that the grounded approach could be used successfully as it led to a number of emergent categories which could then be used to set up a coding scheme for the probes. In addition, it became clear that a second level of coding was required that separated positive and negative impact issues. The overall coding also led to a division of factors into intrinsic and extrinsic issues that related

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[2] In her physics honours project Majiet's (2016) objective was to investigate student views on the role of experimentation in physics. She used the question 5 of the PPLQ instrument as a research tool. In analyzing the free writing responses, which was not done in the present thesis, the observation that the question is phrased ambiguously was confirmed. The responses also confirmed that students interpreted the context of the question as experiments done in their first year lab or experiments in a general physics lab and as such suggested that question 5 should be revised to probe either the local or global context for clarified responses. The responses could not be analyzed using a grounded approach as we did for the ENJ and LRN probe because there were no identifiable issues to form categories. Alternative to the grounded analysis the responses were ranked according to sophistication using the Perry scheme approach (Perry, W. 1979). The conclusion of the project shows that “the way respondents framed their responses indicated that the current labs give the impression that a ’right answer’ exists and that this correct answer is what should be worked towards during the labs”. Following the Perry scheme Majiet found that this framing falls in line with the first stage of Dualism.

either directly to the task at hand or to the broader environmental setup. In addition, both cognitive and emotional issues were apparent.

In the present study we have clearly shown that the physics laboratory environment is a complicated space. The results from data of the present study clearly shows three aspects of the lab (cognitive, emotional and social aspects) which have to be taken into account when dealing with lab reform. In probing students' learning and enjoyment of the lab, two reason categories were constructed based on the category's extrinsic and intrinsic nature to the lab task. These categories are further viewed in a perspective of students' locus of control. Here it is apparent that factors that are extrinsic to the lab task are also external to students' locus of control and, likewise, factors that are intrinsic to the task can also be perceived as internal to students' locus of control. With these constructs, it is clear that issues under the intrinsic group can be identified and addressed technically. On the other hand, the issues that are external to students' locus of control need to be addressed in a different manner because of their largely social and emotional nature.

Framing as one of the cases mentioned will determine the sparseness or richness of network resources that are activated for potential use by the working memory system. The extrinsic and intrinsic construct also forms part of aspects of framing e.g. marks system and instruction material (examples of extrinsic factors) are some of the indicators that emerged in the data. Thus, the extrinsic and intrinsic factors also contribute to the prediction of the quality of engagement and should be taken into serious consideration when developing and maintaining laboratory courses. Hence the importance of clarity of purposes, where each activity in the lab is concerned, should take precedence in the lab. For example, there appears to be a mixed message in terms of stating what the goal of the lab is and the meta-message that actually emerges while carrying out the task.

Another example is that of marks, which can be used for both summative and formative assessment. The way they appear to be used in the labs appears to be a mix of the two, therefore tending to cause frustration to students, who, while they might have learnt something, are penalized for learning. Perhaps the way in which the lab is assessed should clearly separate out the formative and summative assessment to avoid the student being penalized for learning, while in the summative mode students can then be clearly penalized for not having learned in the formative phase.

The first year labs appear to have the potential to foster engagement with the broader scientific method in a complex environment and also to develop scientific thinking skills. However, this depends on the quality of engagement that takes place in the lab. The Idea Space is suggested as a model to be explored in future work as a way of dealing with the overall matrix of factors that span both the cognitive and the affective, and thereby addressing the quality of engagement. part of further study would be to explore the possibility that the framework of extrinsic and intrinsic constructs, including the students' locus of control used in the present study, is open when predicting the quality of engagement using the Idea Space Model.

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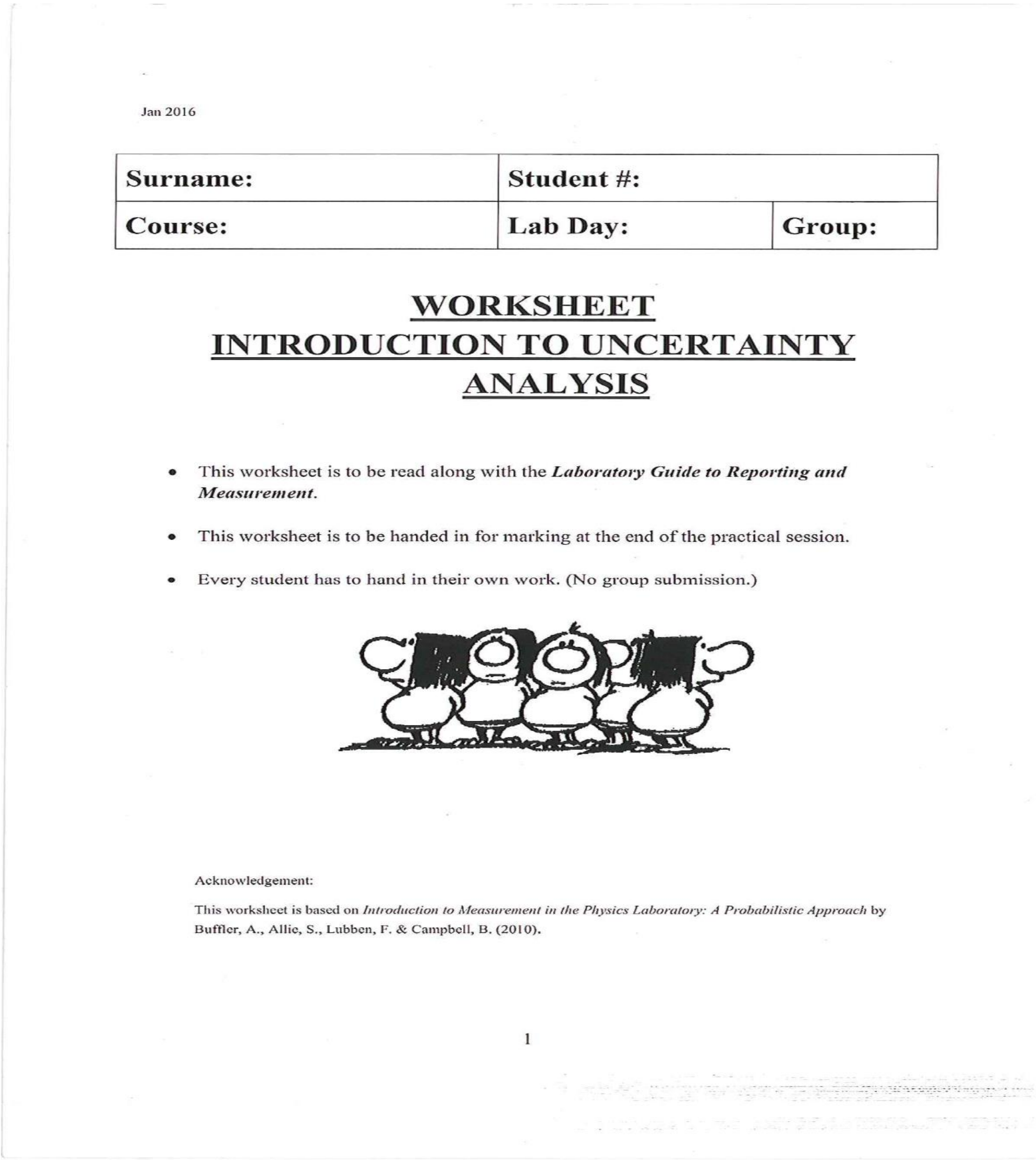
Appendix 1 **INTRODUCTION TO UNCERTAINTY ANALYSIS WORKSHEET**



Jan 2016

Surname:	**Student #:**	
Course:	**Lab Day:**	**Group:**

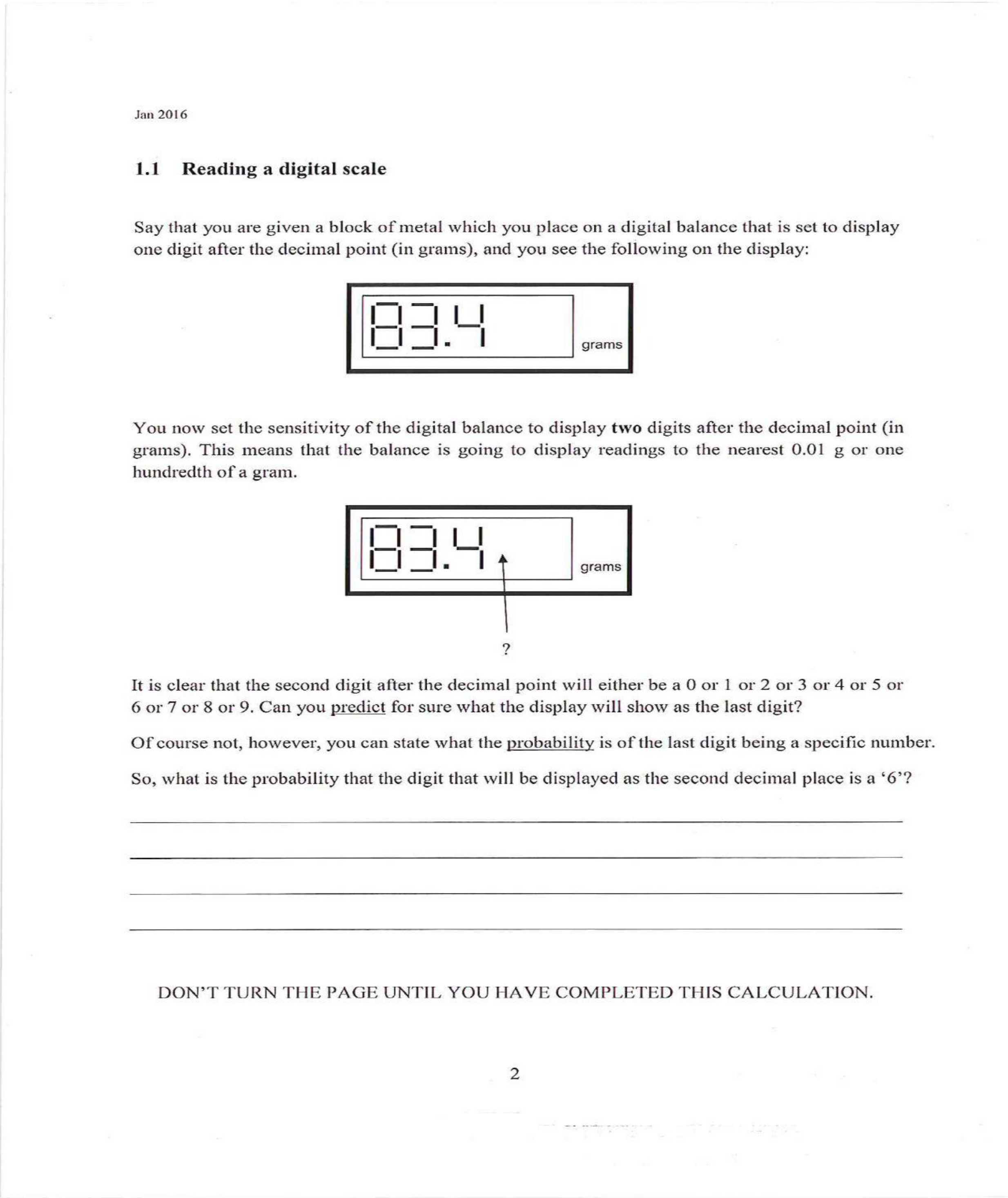
WORKSHEET
INTRODUCTION TO UNCERTAINTY ANALYSIS

- This worksheet is to be read along with the ***Laboratory Guide to Reporting and Measurement***.
- This worksheet is to be handed in for marking at the end of the practical session.
- Every student has to hand in their own work. (No group submission.)

Acknowledgement:

This worksheet is based on *Introduction to Measurement in the Physics Laboratory: A Probabilistic Approach* by Buffler, A., Allie, S., Lubben, F. & Campbell, B. (2010).

1



Jan 2016

1.1 Reading a digital scale

Say that you are given a block of metal which you place on a digital balance that is set to display one digit after the decimal point (in grams), and you see the following on the display:

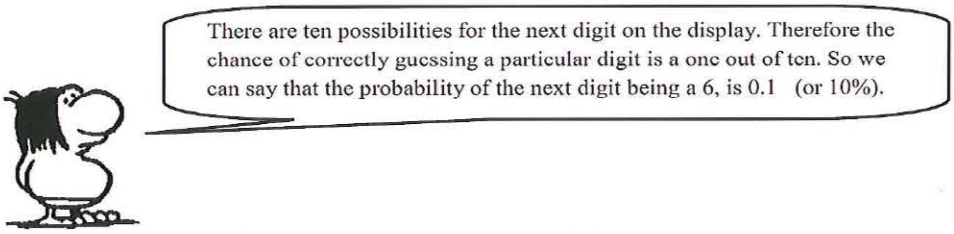
You now set the sensitivity of the digital balance to display **two** digits after the decimal point (in grams). This means that the balance is going to display readings to the nearest 0.01 g or one hundredth of a gram.

It is clear that the second digit after the decimal point will either be a 0 or 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9. Can you predict for sure what the display will show as the last digit?

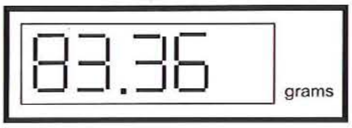
Of course not, however, you can state what the probability is of the last digit being a specific number.

So, what is the probability that the digit that will be displayed as the second decimal place is a ‘6’?

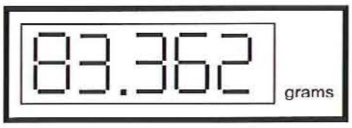
DON’T TURN THE PAGE UNTIL YOU HAVE COMPLETED THIS CALCULATION.



Before you looked at the display, there was no way of predicting with a greater certainty than 10% that the last digit would be a 6. Now you see the following on the display.



Next, the digital balance is set to display **three** digits after the decimal point (in grams) i.e. the balance will now display the reading to the nearest 0.001 g, and you see:



Would it be possible to design and build an electronic balance that could display a reading with an **infinite** number of decimal places? Explain.

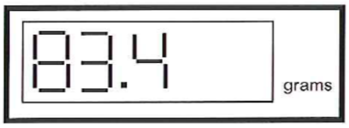
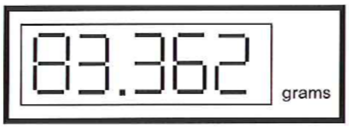
____

____

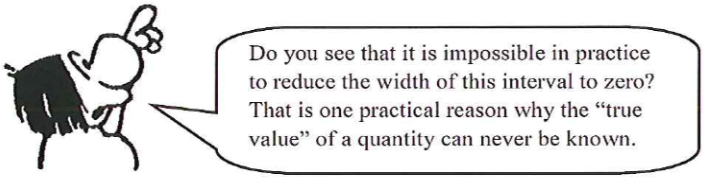
____

____

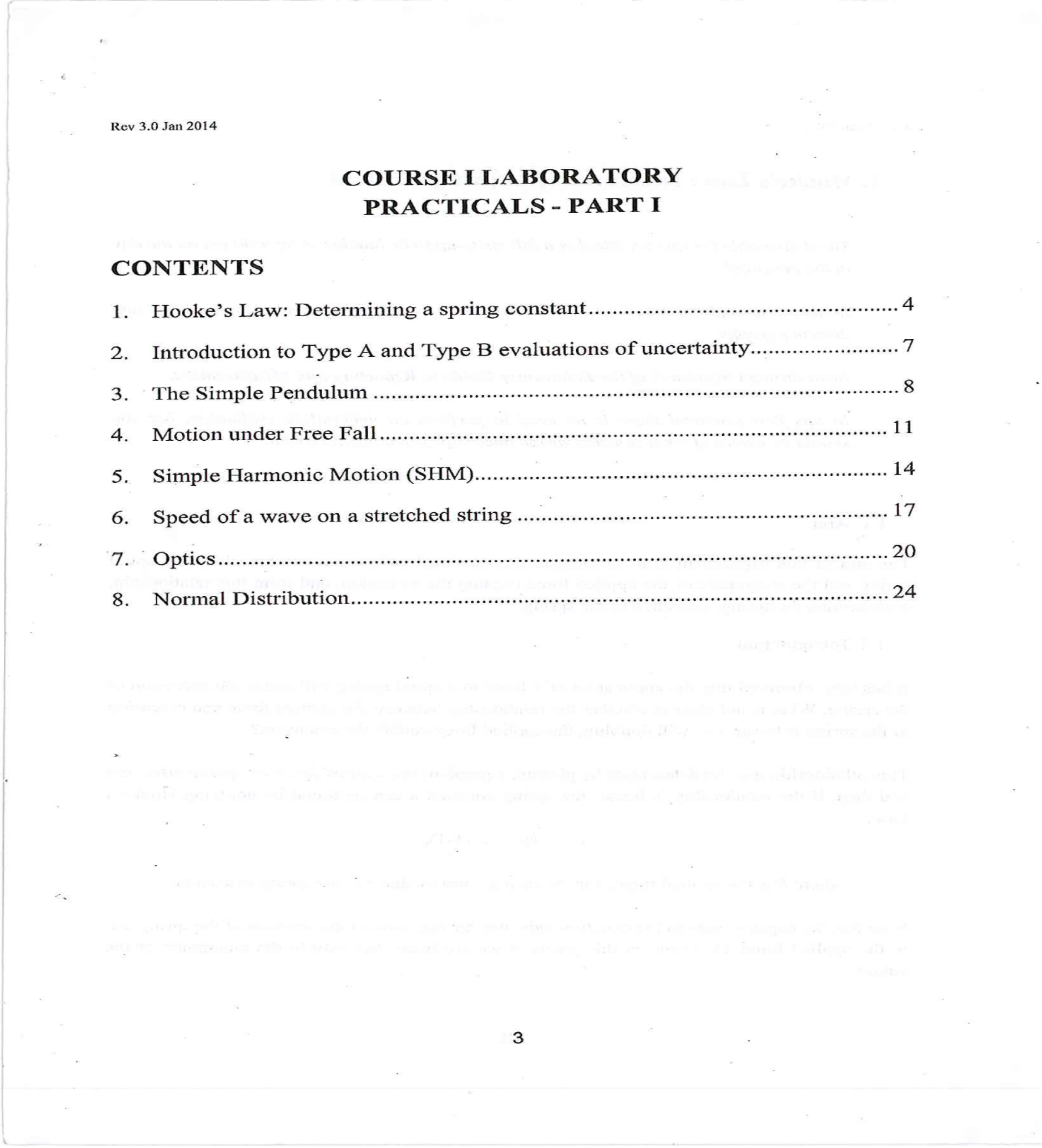
Let us now consider what we know about the mass of the block in each case, **based only on the <u>reading</u> on the digital balance.**

The display shows:	Inference about the mass of the block, based only on the reading:
	The mass of the block lies between 83.35 g and 83.45 g.
	The mass of the block lies between 83.355 g and 83.365 g.
	The mass of the block lies between _________ g and _________ g.

In each case above, we can say that the mass of the block lies somewhere on an <u>interval</u>, the width of which reduces in size as the sensitivity of the electronic balance increases.



Appendix 2 PHY1023H COURSE LABORATORY MANUAL



Rev 3.0 Jan 2014

COURSE I LABORATORY
PRACTICALS - PART I

CONTENTS

1. Hooke's Law: Determining a spring constant

The deliverable for this practical is a full write-up to be handed in by 5:00 pm on the day of the practical.

In this practical the emphasis is on structuring the report, tabulating readings and drawing graphs.

*Read through **Section A** of the **Laboratory Guide to Reporting and Measurement**.*

In this first practical there is no need to perform an uncertainty evaluation, but you should be aware of what is meant by the uncertainty in a measurement.

1.1 Aim

The aim of this experiment is to investigate the relationship between an extension of a spiral spring and the magnitude of the applied force causing the extension, and from this relationship, to determine the spring constant k of the spring.

1.2 Introduction

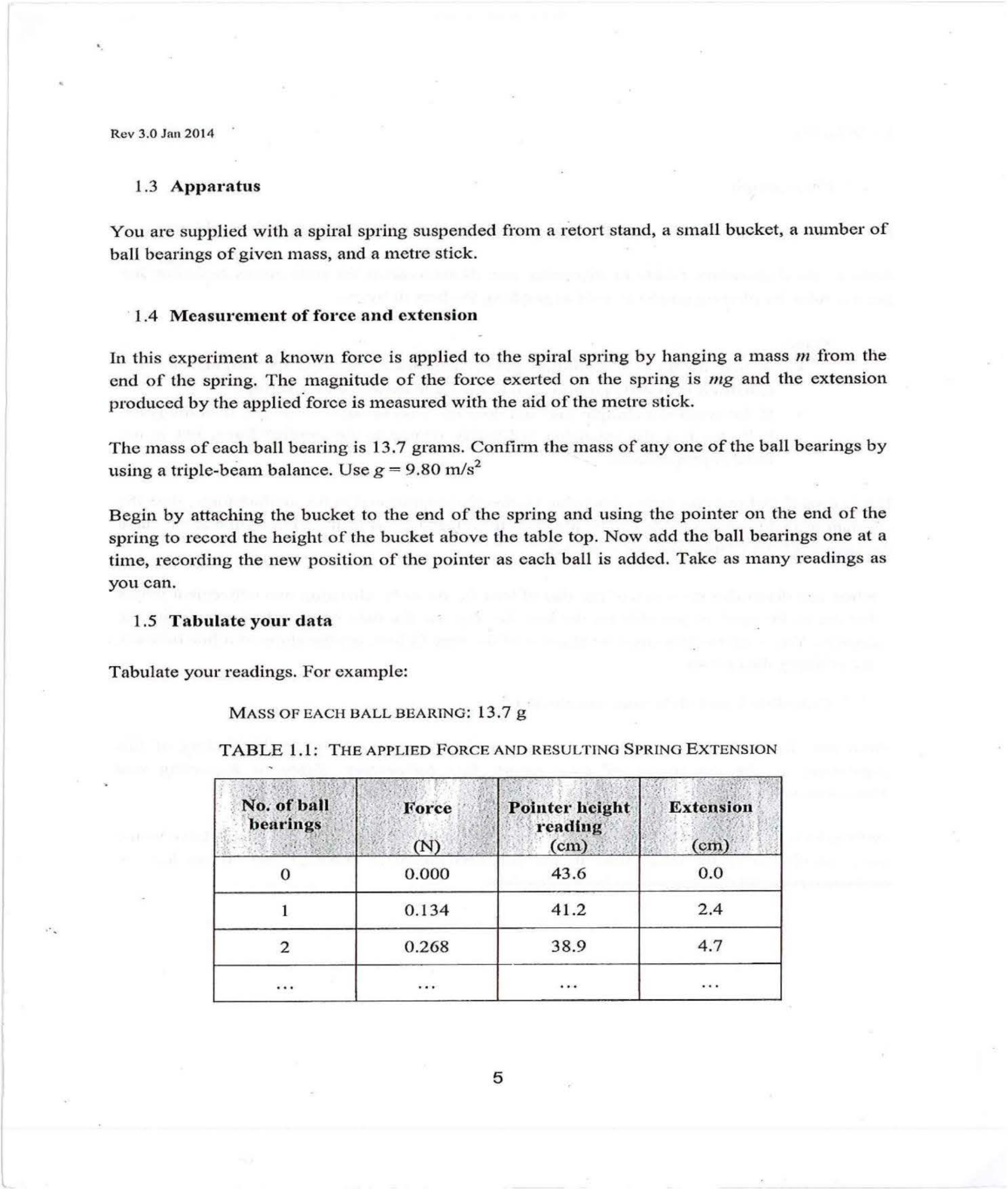
It has been observed that the application of a force to a spiral spring will cause the extension of the spring. What is not clear is whether the relationship between the applied force and extension of the spring is linear, i.e., will doubling the applied force double the extension?

This relationship may be determined by plotting a graph of the *applied force* vs. *spring extension* and then, if the relationship is linear, the spring constant k can be found by applying Hooke's Law:

$$F = -kx \quad \ldots (1\text{-}1),$$

where F is the applied force, k is the spring constant and x is the spring extension.

Note that the negative sign in the equation indicates the direction of the reaction of the spring, kx, to the applied force. However, in this practical we are interested only in the magnitude of the values.



1.3 Apparatus

You are supplied with a spiral spring suspended from a retort stand, a small bucket, a number of ball bearings of given mass, and a metre stick.

1.4 Measurement of force and extension

In this experiment a known force is applied to the spiral spring by hanging a mass *m* from the end of the spring. The magnitude of the force exerted on the spring is *mg* and the extension produced by the applied force is measured with the aid of the metre stick.

The mass of each ball bearing is 13.7 grams. Confirm the mass of any one of the ball bearings by using a triple-beam balance. Use $g = 9.80\ \text{m/s}^2$

Begin by attaching the bucket to the end of the spring and using the pointer on the end of the spring to record the height of the bucket above the table top. Now add the ball bearings one at a time, recording the new position of the pointer as each ball is added. Take as many readings as you can.

1.5 Tabulate your data

Tabulate your readings. For example:

MASS OF EACH BALL BEARING: 13.7 g

TABLE 1.1: THE APPLIED FORCE AND RESULTING SPRING EXTENSION

No. of ball bearings	**Force** (N)	**Pointer height reading** (cm)	**Extension** (cm)
0	0.000	43.6	0.0
1	0.134	41.2	2.4
2	0.268	38.9	4.7
…	…	…	…

1.6 Plot a graph

Plot the data on a graph of *force* (y-axis) vs. *extension* (x-axis) and draw a best fit line by eye.

Refer to the ***Laboratory Guide to Reporting and Measurement*** for instructions regarding the general rules for plotting graphs as well as graphing the best fit by eye.

Note:

- If you obtain a straight-line graph that passes through the origin, then the extension is directly proportional to the force exerted on the spring.
- If the graph is a straight line, but does not pass through the origin, then the graph indicates that the extension is linearly related to the applied force, but is not directly proportional.

If it is established that the spring extension is directly proportional to the applied force, then the constant of that proportionality can be obtained from the slope m of the straight-line graph since the equation for a straight line is $y = mx + c$.

When you determine the slope of the line of best fit, do so by choosing two convenient points that are as far apart as possible on the line. Do not use the data points when calculating the slope m. You need to determine the slope m of the best fit line, not the slope of a line between two arbitrary data points.

1.7 Calculate k and state your conclusion

From the slope of the graph, determine the spring constant and quote the finding of this experiment in the conclusion of your report. See ***Laboratory Guide to Reporting and Measurement.***

IMPORTANT: You must include, in your report, a list of all the sources that you believe would have contributed to the uncertainty in the measurement of k, although you do not have to evaluate (quantify) the uncertainty in this practical.

2. Introduction to Type A and Type B evaluations of uncertainty

This activity involves an exercise in analysing a set of data and performing a Type A evaluation of uncertainty as well as a Type B evaluation of uncertainty.

Depending on the course for which you are registered, this practical will be done either in class or in a laboratory session. In either case, a separate worksheet will be used so there is no need for you to use your lab book.

The completed worksheet is to be handed in at the end of the session. In preparation, students should read through ***Section B*** of the ***Laboratory Guide to Reporting and Measurement.***

3. The Simple Pendulum

The deliverable for this practical is a full write-up to be handed in by 5:00 pm on the day of the practical. In this practical the emphasis is on using Excel to do calculations, to plot a graph, and to perform a Type A evaluation of uncertainty.

3.1 Aim

The aim of this practical is to investigate the relationship between the length of a simple pendulum and its period of oscillation; and from this relationship, to determine the gravitational acceleration g.

3.2 Introduction

A pendulum consisting of a bob (a mass) attached to a string is set up so that the pendulum can swing freely in a vertical plane. As an idealisation we assume that the total mass of the pendulum is concentrated at the centre of the bob.

Provided that the angle through which the bob swings is relatively small, i.e., $\theta_{max} \leq 15°$, the period of oscillation of the pendulum is independent of the mass of the bob (you may wish to confirm this). So, in the idealised case, the period of a simple pendulum depends only on the length of the pendulum, viz.

$$T = 2\pi\sqrt{\frac{L}{g}} \, . \qquad \ldots \ (3\text{-}1)$$

By rearranging the equation (3-1) above it is possible to find g in terms of L and T:

$$g = 4\pi^2 \frac{L}{T^2} \quad . \qquad \ldots \ (3\text{-}2)$$

The equation in the form given in (3-1) above gives an 'unfriendly' graph if T vs L is plotted, so we simplify the graph by linearising the equation as shown in equation (3-3):

$$T^2 = \frac{4\pi^2}{g} L \, . \qquad \ldots \ (3\text{-}3)$$

Read up about **Linearising equations** in the ***Laboratory Guide to Reporting and Measurement*** and note that when a graph of T^2 vs L is plotted it produces a straight line of the form $y = mx + c$.

Since the gradient $m = \frac{4\pi^2}{g}$, one can determine g from the gradient m of the line of best fit.

3.3 Method

To reduce the uncertainty in a measurement of this sort it is always better to determine the time taken for several successive oscillations or cycles and then to divide the total time by the number of oscillations completed. Typically, recording the total time over 20 oscillations will be suitable and from the recorded value of $20T$ you can calculate T.

Record a set of ten (10) data pairs, (L_i, T_i), for $i = 1, 2, 3, \ldots, 10$, where the pendulum length, L, varies between 0.5 m and 1.5 m.

a) From these ten data pairs, (L, T), use equation (3-1) to calculate g for each pair. This will give you a set of ten calculated values for g. Now, using an EXCEL spreadsheet, use the formulae given in **Section B3** of the ***Laboratory Guide to Reporting and Measurement*** to calculate the mean, $\overline{g}$, the standard deviation σ, and the standard uncertainty, $u(g)$.

b) From the ten data pairs, (L, T), calculate (L, T^2) and then use Excel's graphing function to plot T^2 vs L. Show the equation of the best fit line on the graph. See **Using EXCEL** in the ***Laboratory Guide to Reporting and Measurement***. Print the graph and stick it in your laboratory book.

3.4 Analysis, results, discussion and conclusion

For your convenience, an Excel file called pendulum.xls has been placed on the laboratory PCs and an example of a typical printout is included in this set of instructions. You may set up your own Excel tables, or you may make use of the template provided.
Save your work, print out the table and the graph, and paste the printed Excel spread sheet in the RESULTS section of your report.

In your discussion and conclusion:

- Compare the result you got using the formulae, in a) above, with a given value of $g = (9.79824 \pm 0.00044)\ \text{m/s}^2$. See **Comparing results** in the ***Laboratory Guide to Reporting and Measurement***.
- Comment on the best approximation for g that you can get from the gradient m of the EXCEL graph in b) above.

- Comment on whether the y-intercept that you get from the fitted line equation of the graph is equal to 'zero' or not.
- Include an uncertainty budget. See **The uncertainty budget** in the ***Laboratory Guide to Reporting and Measurement.***
- Propose ways to improve the experiment.

Example of a typical spread sheet printout (graph is not shown)

Example: Pendulum spreadsheet - (Use your own data)

Table1: Measurement of period of simple pendulum at different lengths to determine g

Reading #	L (m)	$20T$ (s)	T (s)	T^2 (s^2)	g (m/s^2)		L (m)	T^2 (s^2)
1	0.495	28.26	1.428	2.039	9.583		0.495	0.245
2	Fill in the gaps							
3	Fill in the gaps							
4	0.706	33.90	1.695	2.873	9.701		0.706	0.498
5	Fill in the gaps							
6	1.103	42.78	2.139	4.575	9.517		1.103	1.217
7	Fill in the gaps							
8	1.295	46.20	2.31	5.336	9.581		1.295	1.677
9	Fill in the gaps							
10	1.503	49.52	2.476	6.131	9.679		1.503	2.259

Table 2: Calculation of the standard deviation of g

Reading #	g (m/s^2)	$g_i - g_{ave}$ (m/s^2)	$(g_i - g_{ave})$^2 (m^2/s^4)
1	9.583	-0.029	0.0009
2	Fill in the gaps		
3	Fill in the gaps		
4	9.701	0.089	0.0079
5	Fill in the gaps		
6	9.517	-0.095	0.0091
7	Fill in the gaps		
8	9.581	-0.031	0.0010
9	Fill in the gaps		
10	9.679	0.067	0.0045
Sum	48.061	0.000	0.0232
Ave	9.612		

Use the equations for TYPE A evaluation that are in the *Guide*

Mean	g_{ave} =	9.612	m/s^2
Standard deviation	σ =	0.071	m/s^2
Standard uncertainty	$u(g)$ =	0.022	m/s^2

4. Motion under Free Fall

The deliverable for this practical is a full write-up to be handed in by 5:00 pm on the day of the practical. In this practical the emphasis is on doing a least squares fit using EXCEL and LinearFit.

4.1 Aim

The aim of this experiment is to measure g, the acceleration due to gravity, by using an apparatus to time the free-fall of a ball-bearing over a known distance.

4.2 Introduction

Straight-line relationships between variables are convenient because it is easy to find the coefficients of a straight best fit line. So, if the collected data has a non-linear relationship, we may be able to derive another set of variables from the collected data that does result in our being able to fit a straight line.

In this free-fall practical, the relevant equation in the theory that underpins the description of a mass in free fall is of the form $y = ax^2 + bx + c$, so a graph of y vs. x will not be a straight line. But a graph of y/x vs. x will be a straight line; and we will use this property to analyse the collected data and to extract the information we are after.

4.3 Theory

For a free falling object (ignoring air resistance) we know that

$$y = \frac{1}{2}gt^2 + ut + y_0, \qquad \ldots\ (4\text{-}1)$$

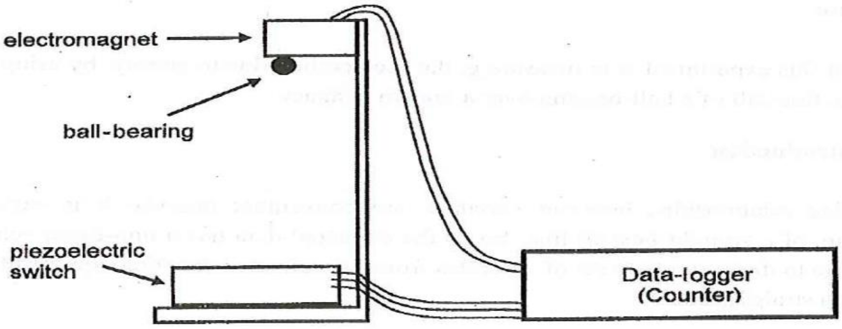
where y_0 is the position and u is the speed of the ball at $t = 0$ s. Clearly a graph of y vs t will not give a straight-line graph. However, dividing both sides of the equation by t ($t \neq 0$) gives:

$$\frac{y}{t} = \frac{g}{2}t + u, \qquad \ldots\ (4\text{-}2)$$

and a plot of y/t vs t should therefore give a straight-line graph of the form $y = mx + c$ with a gradient of $g/2$ and an intercept of u. It can be seen that if the timer does indeed begin timing as the ball is released, the intercept will be zero, if not, there will be an offset, and $u \neq 0$ m s^{-1}.

4.4 Apparatus

The layout of the apparatus for this experiment is illustrated schematically below. By pressing START on the data-logger the timer is activated and the ball is released. The timer stops automatically when the ball hits the piezoelectric switch moulded into the platform at the bottom of the retort stand. **See operating instructions overleaf.**



The detailed instructions for the data-logger are included overleaf.

4.5 Method

Record the time, t_i, taken for the ball to fall a distance y_i, for: $0.1 \text{ m} \le y_i \le 0.8 \text{ m}$ and $i = 1, 2, \ldots, n$ for $n = 10$. (You must account for the diameter of the ball which is 11.2 mm.)

In other words, tabulate ten data pairs, (t_i, y_i), and calculate $\left(t_i, \dfrac{y_i}{t_i}\right)$, for $i = 1, 2, \ldots, 10$.

Plot a graph BY HAND of y/t vs. t, and draw in a best fit line by eye.

a) Use EXCEL and the equations in **E3 Method of least squares** and **E4 Using Excel**, in the ***Laboratory Guide to Reporting and Measurement*** to calculate $m \pm u(m)$ and $c \pm u(c)$ of the line of best fit. (Paste a print-out of your EXCEL workings into your lab book.)

b) Now use **LinearFit** (See **E5 Using LINEARFIT**) and same data you used in the EXCEL spread sheet to determine $m_{Linearfit} \pm u(m_{Linearfit})$ and $c_{Linearfit} \pm u(c_{Linearfit})$ of LinearFit's best fit line. (You do not need to print out this result, merely record the calculated values in your lab book.)

4.6 Calculation, discussion and conclusion

Calculate two values of $g \pm u(g)$: from a) $m \pm u(m)$ and from b) $m_{Linearfit} \pm u(m_{Linearfit})$ above.

Compare the two calculated results for g and comment on any differences that you may find. Also compare your calculated results with the given value for $g = (9.79824 \pm 0.00044)$ m/s^2.

Discuss the interpretation of $c \pm u(c)$. Is the y-intercept 'zero'? What does this value represent?

Be sure to quote the final results using the correct number of significant figures and decimal places. Also include an uncertainty budget in your conclusion.

Data-logger operating instructions

Device	Action	Status
	Step 1	
Data-logger	***Switch ON*** … and wait for the "Scrolling Instruction Screen".	The LED in the interface box lights up and remains ON.
Electromagnet		After some seconds, the **GREEN & BLUE** LEDs give short flashes to indicate that the electromagnet is ready to receive a ball.
	Step 2	
Data-logger		The data-logger screen instructs operator to insert a ball.
Electromagnet	***Insert ball.***	**GREEN** LED lights up… after a second the **BLUE** LED also lights up.
	Step 3	
Data-logger	***Press*** the **RESET/CLEAR** switch.	The data-logger screen will change to the instruction to press the start switch.
Electromagnet		**GREEN & BLUE** LED's are **ON.**
	Step 4	
Data-logger	***Press*** the **START** switch.	Screen goes blank momentarily.
Electromagnet		The ball is released.
Piezoelectric switch		**BLUE** LED in the recess under the switch flashes briefly as ball hits the surface.
Data-logger		Screen displays the time in seconds.
	Step 5	
Data-logger	***Press*** the **RESET/CLEAR** switch.	Screen goes to scrolling instruction mode.
Electromagnet		**GREEN & BLUE** LEDs start flashing to indicate that the data-logger is ready to take the next reading.
	Return to Step 2	

Appendix 3 **PPLQ**

Student no:

Department of Physics
University of Cape Town
Physics Perceptions Laboratory Questionnaire (PPLQ)

Please note that the data will be analysed anonymously and that you will not be identified to the lecturer. The reason for asking you to fill in your student number is so that the researcher(s) can contact you in order to clarify or expand on your responses.

A number of groups of students are discussing their experiences of the afternoon labs.

Some of the issues they are debating are contained in the pages that follow.

You are asked to join their discussions and <u>offer your opinion</u>.

[XTRa]

A group of students discuss their expectations regarding the physics labs.

Student A says, “So far the labs have been what I expected they would be”.

Student B says, “I don’t agree! The labs turned out to be completely ***not*** what I expected”.

Students C says, “I do not agree with either of you!”

With whom do you most closely agree? (Circle one)

A	B	C

Explain your choice in as much detail as possible.

[ENJa]

Another group of students are debating how much they enjoyed the labs.

Student A says, “I really enjoyed the labs!”

Student B says, “I did not enjoy the labs in the least!”

Student C says,” I don’t agree with either of you!”

With whom do you most closely agree? (Circle one)

A	B	C

Explain your choice in as much detail as possible.

[LRNa]

A third group of students argue about what they learnt in the labs.

Student A says,” I learnt a lot in the lab!”

Student B says,” No! I learnt very little in the lab”

Student C says,” Hang on, I have a different view to both of you”

With whom do you most closely agree? (Circle one)

A	B	C

Explain your choice in as much detail as possible.

[LLRa]

Three students are arguing about the lab versus the theory part of the course.

Student A says, “I did not like the labs as they did not help us with lectures or problems sets”.

Student B says, “You are confused! The labs were not meant to do that in the first place”.

Student C says, “I don’t agree with any of you!”

With whom do you most closely agree? (Circle one)

A	B	C

Explain your choice in as much detail as possible.

[THXPa]

A group of students disagree about the experiments and theory.

Student A says, “The main aim of experiments in physics is to prove the theory correct”

Student B says, “No! The main aim of experiments in physics is to discover new things”

Student C says, “I have a different view to both of you”

With whom do you most closely agree? (Circle one)

A	B	C

Explain your choice in as much detail as possible.

Appendix 4 TABLE OF CALCULATED VALUES FOR ERROR BARS AT A 95% CONFIDENCE LEVEL

Probe	Total	Proportions2	Upper limit	Lower limit	Lower L differ	Upper l diff
Expectations	100					
		50	59.62	40.38	9.62	9.62
		37	46.78	28.18	8.82	9.78
		13	20.98	7.76	5.24	7.98
Enjoyment	100					
		28	37.49	20.14	7.86	9.49
		42	51.79	32.8	9.2	9.79
		30	39.58	21.89	8.11	9.58
Learning	100	100				
		52	61.54	42.32	9.68	9.54
		24	33.23	16.69	7.31	9.23
		22	31.07	15	7	9.07
		2	7	0.55	1.45	5
Lab and Lectures	100					
		26	35.37	19.17	6.83	9.37
		32	41.66	24.78	7.22	9.66
		36	45.76	28.63	7.37	9.76
		6	12.48	2.78	3.22	6.48
Theory and Ex	100					
		43	52.78	33.73	9.27	9.78
		19	27.78	12.51	6.49	8.78
		34	43.72	25.46	8.54	9.72
		4	9.84	1.57	2.43	5.84

Appendix 5 **ERROR BAR CALCULATIONS**

The Confidence Interval of a Proportion:

The web calculator was used from the site: http://vassarstats.net/prop1.html

This unit will calculate the lower and upper limits of the 95% confidence interval for a proportion, according to two methods described by Robert Newcombe, both derived from a procedure outlined by E. B. Wilson in 1927 (references below). The method uses the Wilson procedure without a correction for continuity.

For the notation used here, n = the total number of observations and k = the number of those n observations that are of particular interest. Thus, if one observes 23 recoveries among 60 patients, n = 60, k = 23, and the proportion is 23/60 = 0.3833.

To calculate the lower and upper limits of the confidence interval for a proportion of this sort, enter the values of k and n in the designated places, then click the «Calculate» button.

References:

Newcombe, Robert G. "Two-Sided Confidence Intervals for the Single Proportion: Comparison of Seven Methods," *Statistics in Medicine*, **17**, 857-872 (1998).

Wilson, E. B. "Probable Inference, the Law of Succession, and Statistical Inference," *Journal of the American Statistical Association*, **22**, 209-212 (1927).

Appendix 6 **TABLE 5-2 CALCULATIONS**

Extrinsic

ENJ (P) = SSP (15) + SDP (2) + MKP (4) + TMP (3) + IMP (0) + LRN (4) + LLN (1) = 29

ENJ (N) = SSN (7) + SDN (8) + MKN (5) + TMN (26) + IMN (9) + LRP (1) + LLP (1) = 57

Intrinsic

ENJ I (N) = UAN (6) + DAN (5) + ITN (8) + UCN (12) + EKN (1) + RWN (8) + PXN (9) + BKN (1) = 50

ENJ I (P) = UAP (2) + DAP (7) + ITP (5) + UCP (20) + EKP (9) + RWP (1) + PXP (15) + BKP (0) = 59

Extrinsic

LRN (P) = SSN (6) + SDN (0) + MKN (1) + TMN (8) + IMN (1) + LRP (4) + LLP (5) = 25

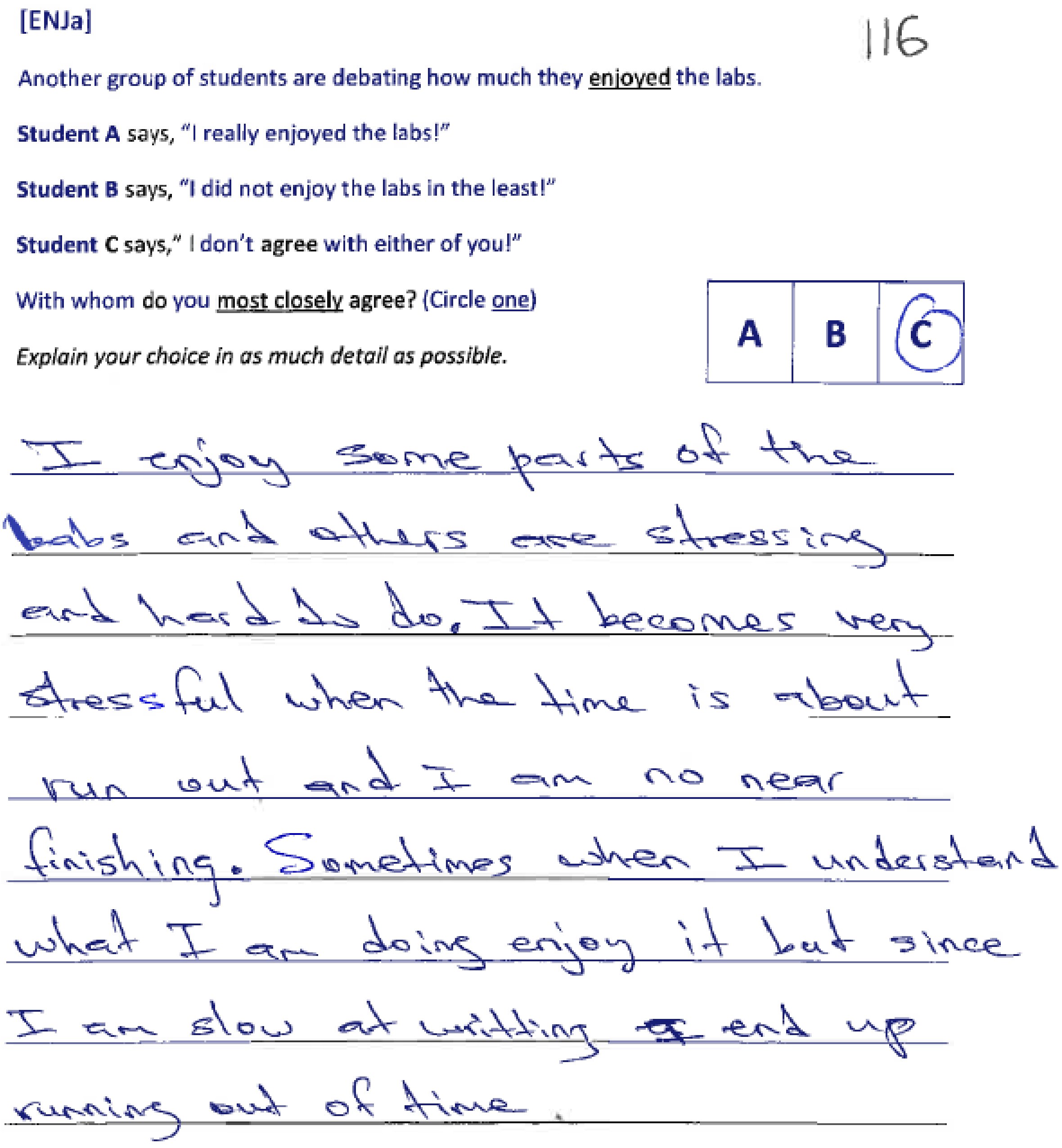
LRN (N) = SSP (2) + SDP (3) + MKP (2) + TMP (8) + IMP (3) + LRN (1) + LLN (6) = 25

Intrinsic

LRN I (P) = UAP (12) + DAP (6) + ITP (12) + UCP (19) + EKP (8) + RWP (5) + PXP (32) + BKP (5) =99

LRN I (N) = UAN (3) + DAN (0) + ITN (0) + UCN (18) + EKN (0) + RWN (3) + PXN (10) + BKN (3) = 37

Appendix 7 EXAMPLE OF STUDENT SCRIPTS



[ENJa]

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Another group of students are debating how much they enjoyed the labs.

Student A says, "I really enjoyed the labs!"

Student B says, "I did not enjoy the labs in the least!"

Student C says," I don't agree with either of you!"

With whom do you most closely agree? (Circle one)

A B [✓ C]

Explain your choice in as much detail as possible.

I enjoy some parts of the labs and others are stressing and hard to do. It becomes very stressful when the time is about run out and I am no near finishing. Sometimes when I understand what I am doing enjoy it but since I am slow at writting ~~I~~ end up running out of time.

[LRNa]

126

A third group of students argue about what they learnt in the labs.

Student A says," I learnt a lot from the labs!"

Student B says," No! I learnt very little in the lab".

Student C says," Hang on! I have a different view to both of you".

With whom do you most closely agree? (Circle one)

Explain your choice in as much detail as possible.

[✓ **A**] **B** **C**

My choice is A because I'm one of those people who learn alot. I get to know the difference between different variables and come up with solutions for particular problems. And also because of the experiments I learn new stuff.

Appendix 8 **100 × 2 WR ANALYSIS OF THE LEARNING AND ENJOYMENT PROBE**

Code	Description	Code	Description
MK_P MK_N	Marks	UA_P UA_N	Uncertainty analysis
EX_P EX_N	Experiments	IT_P IT_N	Integrating Technology
SS_P SS_N	Student-Student Relationship	DA_P DA_N	Data Analysis
SD_P SD_N	Student-Demonstrator Relationship	UC_P UC_N	Understanding Concepts
TM_P TM_N	Time	EK_P EK_N	Expert like Knowledge
RW_P RW_N	Report Writing	IM_P IM_N	Instructional Manuals/Material
LR_P LR_N	Lab Resources	BK_P BK_N	Prior Background Knowledge
LL_P LL_N	Lecture-Lab Correlation		

Enjoyment						**Learning**						
RIN	**ENJ-FCR**	**Codes**				**RIN**	**LRN-FCR**	**Codes**				
101	A	SS_P	SD_P			101	A	LR_P	IT_P			
102	A	LL_P	TM_N	TM_P		102	C	LL_P	UC_P	UC_N		
103	A	PX_P	DA_P	IT_P		103	A	BK_P	IT_P			
104	A	UC_P				104	A	BK_P				
105	A	PX_P	UC_P	SS_P		105	A	LL_N				
106	A	PX_P	PX_P	UC_P		106	A	UC_P	PX_P			

107	A	SS_P				107	B	IT_P	PX_P	PX_N		
108	A	UC_P				108	A	TM_P	UC_P			
109	A	EK_P	UC_P			109	A	BK_P	PX_P	LR_P		
110	A	SS_P	PX_P			110	A	SS_P	PX_P			
111	A	RW_P	MK_P			111	C	IT_P	SS_P	UC_N		
112	A	LR_P	SD_P	TM_P		112	A	LR_P	UA_P			
113	A	PX_P				113	A	EK_P	LL_P			
114	A	EK_P	MK_P			114	A	PX_P				
115	A	LR_P	IT_P			115	A	LR_P	PX_P			
116	C	TM_N	UC_P			116	A	LL_P	PX_P			
117	A	PX_P	TM_N			117	A	PX_P				
118	A	PX_P	EK_P	DA_P		118	A	BK_N				
119	A	SS_P	DA_P			119	A	UA_P	PX_P			
120	B	UC_N	IM_N			120	A	PE_P				
121	A	SS_P				121	C	LL_N				
122	A	SS_P				122	A	LL_	UC_			
123	A	SS_P	UA_N			123	C	UA_N				
124	A	PX_P	EK_P			124	A	DA_P	UA_P	SS_P		
125	A	EK_P	UC_P	EK_P		125	A	IT_P				
126	A	PE_P	UC_P	UC_P		126	A	UC_P	PE_P			
127	A	UC_P	SS_P	SS_P		127	A	PE_P	RW_P	TM_P	TM_N	
128	A	UC_P	SS_P	EK_P		128	A	EK_P	UC_P			
129	A	IT_P	IT_P	DA_P	DA_P	129	A	UA_P	UC_P			

130						130	A	UA_P	BK_P			
131	B	PX_N				131	B	PX_P				
132	B	UA_N	DA_N	UA_P		132	B	LL_N	PX_N			
133	B	UC_N				133	B	UC_N				
134	A	UC_P	UC_P			134	C	UC_P				
135	B	UC_N	TM_N			135	B	IM_N	UA_N			
136	B	TM_N	PX_N			136	C	PX_P	TM_P			
137	B	UC_N				137						
138	B	PX_N				138	PX_P					
139	B					139	B	UC_N				
140	C	MK_N	PX_P			140	A	PX_P	UC_P			
141	B	TM_N	PX_P			141	B	TM_N	UC_N			
142	B	SD_N	IM_N	SD_N		142	C	PX_N	RW_P			
143	B	TM_N	EK_N			143	B	UC_N				
144	B	TM_N	PX_N			144	B	TM_N	UC_N			
145	B	SS_N	SD_N	MK_N		145	C	LL_P	LL_N	PX_P		
146	B	TM_N	PX_N			146	C	SD_N	UC_N			
147	C					147	C	BK_N	PX_P	LL_P		
148	B	UC_N	TM_N			148	A	IT_P	TM_P			
149	B	UA_N	UA_P			149	A	UC_P	PX_P			
150	B	TM_N	TM_N			150	B	LL_N				
151	B					151	B	DA_P	PX_N			
152	B					152	A	PX_P				

153	B	CU_N	TM_N			153	B	PX_P	UC_N			
154	B	LL_N				154	A	IT_P	PX_P			
155	B	TM_N				155	B	IM_N	PX_N			
156	B	MK_N	MK_N	BK_N	MK_N	156	B	MK_N				
157	B	PE_N	RW_N	UA_N	DA_N	157	C	LL_N	UA_P			
158	B	TI_N	RW_N			158	A	PX_P	EK_P			
159	B	IM_N	TI_N			159	C	UC_N	IM_N	UC_P		
160	B	UC_N	IM_N			160	C	RW_N	UC_N			
161	B	SS_N	SS_N	IT_N		161	A	PX_P	UC_P			
162	B	LR_P				162	A	PX_P	UA_P			
163	B	UC_N	SD_N			163	B	UC_N				
164	B	SS_N	TM_N			164	B	UC_P	MK_N	UC_N		
165	B	UC_N				165	C	PX_N	PX_P			
166	B	RW_N	TM_N	UC_P		166	A	PX_P	UA_P			
167	B	IM_N	IT_N			167	C	PX_N	EK_P			
168	B	PX_N				168	B	PX_N	RW_N			
169	B	TM_N				169	A	PX_P	IT_P			
170	B	IM_N				170	B	BK_N				
171	B					171	B	PX_N	SD_N			
172	B	LR_N	TM_N	RW_N	IT_N	172	B	UA_N	SD_N			
173	C	PE_P	RW_N			173	B	UC_N	UC_N			
174	C	UA_N	DA_N			174	C					
175	C	SS_P	DA_N	DA_P	DA_N	175	A	TM_P	DA_P	RW_P		

176	C	TM_P	TM_N	RW_N		176	A	PX_P	RW_P			
177	C					177	A	EK_P				
178	C	PX_N	EK_P			178	A	DA_P	PX_N			
179	C	SS_P	TM_N			179	C	TM_N	UC_N			
180	C	TM_N				180	B	TM_N				
181	C	TM_N	EK_P			181	A	PX_P	IT_P	SS_P	TM_P	
182	C	UC_P	UC_N	SD_N		182	B	TM_N	PX_N	RW_N		
183	C	LR_P	IT_N	IM_N		183	C					
184	C	TI_N	DA_P			184	A	UA_P	DA_P	RW_P	PX_P	
185	C	SS_N	SS_P			185	A	PX_P	TM_P			
186	C					186	A	UC_P				
187	B	SS_N	IM_N	SD_N	SD_N	187	C	IT_P	IM_P	SS_N	UC_P	SS_N
188	C	PX_P	PX_N			188	A	UC_P				
189	C	UC_N	IT_P			189	C	UC_P	UC_N			
190	C	SS_P	PX_P	TM_N		190	A	UA_P	UC_P			
191	C	PX_P	UA_N			191	A	UA_P	SS_P	UC_P		
192	C	SS_P	UC_P	TM_U	RW_N	192	C	PX_P	IT_P	UC_N		
193	C	MK_P				193	A	UC_P	EK_P			
194	C					194	A	DA_P	IT_P			
195	C	SS_N	UC_N	TM_N	UC_P	195	B	TM_N	TM_P	MK_P		
196	C	TM_N	MK_P	UC_P		196	A	TM_N	EK_P			
197	C	UC_P	TM_N	SD_N	RW_N	197	A	EK_P	PX_P	SS_P		
198	C	PX_N	IM_N			198	C	UA_P				

199	C	TM_N	UC_P	PX_P		199	A	PX_P				
200	C					200	Invalid					

Appendix 9 ABSTRACTS FOR THE WORLD CONFERENCE OF PHYSICS EDUCATION 2012 ISTANBUL TURKEY

The Idea Space: Friends, footholds, and fear: impacts on physics learning (Part 1)

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Over the past several years, the University of Cape Town (UCT) and Oregon State University (OSU) have been collaborating on a number of research projects all with a central theme of understanding learning affordances. This work, combined with other research, has led us toward developing a generalizable cognitive framework that can be used to develop research-based curricular materials. The key concept is centered around the notion of what we have termed the "idea space", using a geometrical metaphor to describe the interplay between two components that operate at the cognitive level, namely the available (and maximally limited) working memory and the network of cognitive resources that are primed for potential use. We posit that the quality of engagement with a question is related to the size of this space. Thus, if students end up having a large 'idea space' when approaching a learning task more meaningful engagement will take place. Conversely, if a small idea space is created as a result of either compromising available working memory and / or because of a weak network of resources at hand, engagement with the task will be of low quality. For example, one way in which working memory can be compromised is through off-task monitoring. The priming of a larger or smaller network of resources depends on the way in which questions are posed to the students. An example of how different question types would activate different idea spaces follow. Consider the question, "Will air resistance affect the motion of the object?" as opposed to the question "Make a list of all the possible factors that you consider could affect the motion of the object and next to each write down if you think it will have a large or small effect." The former question puts a student in the frame of recalling authoritative information and being either correct or incorrect with only two possible choices: yes or no. The latter question "opens the idea space" and allows the student freedom to express understanding about multiple aspects of Newton's second law without being limited. Some questions and ways of posing questions potentially activate monitoring functions that use up working memory that could otherwise be used for productive resources. In the above example, expecting a student to give a yes or no answer dictates that they are either correct or incorrect. This could induce fear on the part of an unconfident student, which activates monitoring functions that take up needed working memory. A classic example of monitoring is that of stereotype threat. Research indicates that stereotype threat uses up working memory that crowds out space for problem solving, leading to lower scores for those who fear they will be judged as a stereotype. Thus, fear in general leads to a reduction of the idea space.

The Idea Space: Friends, footholds, and fear: impacts on physics learning (Part 2)

“Friends, footholds, and fear” refers to three key aspects of a cognitive model, the “idea space” (described in Part 1 of the presentation) that can be used as a simple framework for generating and evaluating teaching materials. In short, the bigger the idea space the higher the quality of student engagement. Here we discuss three sets of data that underpinned the development of the model to illustrate their influence on student engagement in the physics classroom.

“Friends” and the impact of perceived audience: In this study students were provided with a worksheet (part of a research instrument) requesting them to report what they had measured during a laboratory experiment that involved scattered data. Three different audiences were posited to each student: the instructor, a friend and a written laboratory report. The most interesting finding was that 74% of the sample in question (#N= 120) answered the same question differently to at least one of the audiences, with 24% answering differently for all three audiences. Even more telling was that fact that the instructor audience was provided with the least acceptable answers in a majority of instances. The main implication is that the perceived audience which follows (usually unconsciously) from the way in which we pose questions impacts the idea space. This was further substantiated in follow up interviews. Thus, posing the question in a way that allowed the student to be the “relative authority” tended to produce more acceptable answers as opposed to questions that were posed by an authority figure and carrying an implied judged for correctness. From the perspective of our model it would appear that in the latter case the idea space is reduced through activating monitoring functions in working memory.

“Footholds” for understanding and conceptual metaphor. The results summarized here come from a study of students’ ideas of density using cognitive linguistics as an interpretative tool. In particular, the study aimed to identify whether any particular ”foothold metaphors”, if any, were more productive than others in promoting a deeper understanding of density in its broader applications. In this study students were asked to explain “density” and/ or “denseness” in words and then to draw an explanatory diagram (to an audience that allowed the student to be the relative authority). This was followed by a question that asked students to predict the equation for “charge density, a concept that they had not previously encountered as all previous scientific contexts involved only mass and volume. It was found that 80% of students who used a “packing” metaphor were able to correctly predict the equation for charge density as opposed to less than 25% of the sample (#N=126) who used other starting footholds. The main implication from this study is that when students ideas are based on appropriate foothold metaphors they will be more successful when extending their knowledge to new contexts. Thus, activities that activate appropriate metaphors effectively leads to an increased idea space.

“Fear” is regarded as one of the main drivers of decreasing the idea space by introducing monitoring functions into working memory as one consequence. A mild form of this notion is already apparent in the study on perceived audience discussed earlier but the effects are further explored here in a study on a group of “special access” postgraduate astrophysics students who transferred into their present university from various undergraduate institutions. The main purpose of the broad (and longitudinal) study was to try and identify issues that impacted negatively on their performance. In one related research exercise the students were given the word “astrophysics” at the centre of an otherwise blank piece of paper and asked to write any words, phrases, images, or diagrams that came to mind on seeing the word. Students were then asked to elaborate about what they had written. Amongst the findings were that students struggled at each level of study with a variety of tensions and conflicts that evolved in different ways as they progressed through their years of graduate study. Results from interviews carried out as part of the broader study show that while some of these tensions involved aspects beyond the immediate academic environment the source of much internal conflict involved academic contradictions that were perceived between their previous and present institutions, and more significantly contradictions within the new academic system. This made it difficult to “read” the system leading to continuous monitoring without arriving at a stable framing of the situation. Thus, students struggle through a process of managing and adjusting to internal conflicts that goes far beyond learning physics content knowledge in order to succeed, even in graduate school. These conflicts give rise to monitoring functions and need to be explicitly addressed in order to optimize engagement at the levels that are required for success.