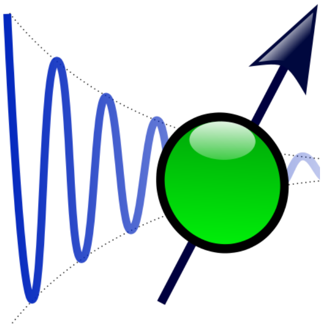

Investigating Physics Investigations in the Stage 1 Laboratory

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After detailing the context of inquiry and investigations in the context of secondary school Science and Physics courses, the ideas from the literature on the significance of scientific and physics laboratory work is provided. The current laboratory programmes for Physics 120, 150 and 160 are analysed and reviewed with the objective of re-developing the laboratory courses for 2013. A summary of recommended developments for the stage 1 Physics laboratories is presented.

Introduction

To investigate what we need to present as the objectives of the Stage 1 Physics Laboratory Course in future years it is necessary to look at both the background learning students bring when entering first year Physics and at what we expect they will learn while they are studying in first year. Currently there are changes being made to the first year courses with some re-arrangement of topics between Physics 120 “Physics of Energy” and Physics 150 “Physics of Technology” and there is significant re-alignment occurring between both of these courses and Physics 160 “Physics for students of medical sciences”. These changes will need to be paralleled by a re-development of the laboratory programme for each of these courses so that there is coherence and close relationships between the re-aligned courses and the laboratory work in 2013.

A comparison of the stage 1 Physics laboratory course objectives from 1968 and 2012 shows little change in what we have always done in the stage 1 physics laboratory work.

1968	2012
The first aim of this laboratory course is to instil basic experimental skills such as a) Your ability to record data in an accessible form. b) Your ability to use laboratory equipment with care and facility and to appreciate their imitations and range of usefulness. c) The development of some ability to interpret experimental data. d) Your ability to realize that in every measurement there is some uncertainty and your ability to acquire some facility in finding te size of this error, in the result. e) You must learn how to improve the accuracy of the result by using as large a range of the variable quantity as possible with the apparatus. f) the ability to recognize which measurements have little or no effect on the accuracy of the result. A second aim is the acquisition of some first-hand knowledge of the experimental basis of the subjects discussed in lectures. A third aim is to develop the ability to criticize accepted authority, with deference. A fourth aim is to develop self-discipline in “theoretical” processes such as ‘arithmetic’, reading of scales, looking at tables etc..	The assessment is based on a mark schedule • pre-lab questions 1 mark • legibility, layout, aim, data recording and analysis 4 marks • critical thinking and understanding 5 marks together with criteria for that lab report on each of aim, results and analysis, discussion and conclusion.

Table 1: The comparison of Physics Stage 1 Laboratory Objectives in 1968 and 2012

Nature of Science strand	The Physical World Strand
Level 7 (Year 12) **Achievement objectives** **Nature of science** *Students will:* **Understanding about science** Understand that scientists have an obligation to connect their new ideas to current and historical scientific knowledge and to present their findings for peer review and debate. **Investigating in science** Develop and carry out investigations that extend their science knowledge, including developing their understanding of the relationship between investigations and scientific theories and models. **Communicating in science** Use accepted science knowledge, vocabulary, symbols, and conventions when evaluating accounts of the natural world and consider the wider implications of the methods of communication and/or representation employed. **Participating and contributing** Use relevant information to develop a coherent understanding of socio-scientific issues that concern them, to identify possible responses at both personal and societal levels.	**Physical world** *Students will:* **Physical inquiry and physics concepts** Investigate physical phenomena (in the areas of mechanics, electricity, electromagnetism, light and waves, and atomic and nuclear physics) and produce qualitative and quantitative explanations for a variety of unfamiliar situations. Analyze data to deduce complex trends and relationships in physical phenomena. **Using physics** Use physics ideas to explain a technological or biological application of physics.
Level 8 (Year 13) **Achievement objectives** **Nature of science** *Students will be :* **Understanding about science** Understand that scientists have an obligation to connect their new ideas to current and historical scientific knowledge and to present their findings for peer review and debate. **Investigating in science** Develop and carry out investigations that extend their science knowledge, including developing their understanding of the relationship between investigations and scientific theories and models. **Communicating in science** Use accepted science knowledge, vocabulary, symbols, and conventions when evaluating accounts of the natural world and consider the wider implications of the methods of communication and/or representation employed. **Participating and contributing** Use relevant information to develop a coherent understanding of socio-scientific issues that concern them, to identify possible responses at both personal and societal levels.	**Physical world** *Students will:* **Physical inquiry and physics concepts** Investigate physical phenomena (in the areas of mechanics, electricity, electromagnetism, light and waves, and atomic and nuclear physics) and produce qualitative and quantitative explanations for a variety of complex situations. Analyze and evaluate data to deduce complex trends and relationships in physical phenomena. **Using physics** Use physics ideas to explain a technological, biological, or astronomical application of physics and discuss related issues.

Table 2: The Levels 7 and 8 New Zealand Curriculum statements relating to the Nature of Science strand and the Physical World strand

http://nzcurriculum.tki.org.nz/Curriculum-documents/The-New-Zealand-Curriculum/Learning-areas/Science/Science-curriculum-achievement-aims-and-objectives

Part 1: Setting the context of student learning before entering first-year Physics

The 2007 New Zealand Curriculum in Science places a much greater emphasis on student learning about the Nature of Science.

The **nature of science** strand is the overarching, unifying strand. Through it, students learn what science is and how scientists work. They develop the skills, attitudes, and values to build a foundation for understanding the world. They come to appreciate that while scientific knowledge is durable, it is also constantly re-evaluated in the light of new evidence. They learn how scientists carry out investigations, and they come to see science as a socially valuable knowledge system. They learn how science ideas are communicated and to make links between scientific knowledge and everyday decisions and actions. These outcomes are pursued through the following major contexts in which scientific knowledge has developed and continues to develop – the living world, planet earth and beyond, the physical world, the chemical world. http://nzcurriculum.tki.org.nz/Curriculum-documents/The-New-Zealand-Curriculum/Learning-areas/Science

An example of a scientific investigation by students in a Physics context is
“**How safe are your sun-glasses?**”

This example investigation is intended to support students to develop inquiry skills; foster lifelong learning skills; develop deeper understanding of a topic that may have related issues and include values; and to learn about research as a process of knowledge building and development. It links the Science, Maths, Social Science and Phys.’Ed.’ Learning Areas to form cross-curriculum links that provide opportunities to evaluate values and utilise the Key Competencies to permeate and link parts of the whole study and student enhance learning. Such inquiry learning study should allow the integrating strands to be brought forward into closer focus and provide an opportunity for greater student involvement at all levels of the study. The integrating strands:

- help students think critically about subject ideas
- are often neglected in some of our teaching
- are central to the future, revised curriculum.

Using both the integrating and contextual strands boosts the overall understanding and teaching of science in the classroom.

The Key Competencies are integrated throughout these studies but are taught explicitly at several stages. While other **Key Competencies** are explicitly emphasised during the development, the main theme or Learning Intention is about **Personal Decision Making** so it relates to **Managing Self**. Students work together to develop ‘Participating and Contributing’ and develop competencies of ‘**using language Symbols and Texts**’ as they develop their understanding of the issues and how to present the report.

The inquiry-based learning in Science is then developed within their Physics Year 12 and 13 years. The current NCEA Achievement Standards are provided on the next two pages as Figures 1 and 2. Note that the Level 3 Achievement Standard is under review and some changes will occur in 2013. The criteria in Figures 1 and 2 show that, after completing Level 3 students should enter Physics at Year 1 with considerable understanding of how to make reliable and accurate measurements, and how to develop a linear mathematical relationship between two variables, and how to evaluate, combine and express uncertainties in Physics based investigation.

Physics Level 2 Achievement Standard 91168 2012

Carry out a practical physics investigation that leads to a non-linear mathematical relationship

Achievement Criteria

Achievement	**Achievement with Merit**	**Achievement with Excellence**
• Carry out a practical physics investigation that leads to a non-linear mathematical relationship.	• Carry out an in-depth practical physics investigation that leads to a non-linear mathematical relationship.	• Carry out a comprehensive practical physics investigation that leads to a non-linear mathematical relationship.

Explanatory Notes

1 *Carry out a practical physics investigation* involves:

- collecting data relevant to the aim based on the manipulation of the independent variable over a reasonable range and number of values
- drawing a graph that shows the relationship between the independent and dependent variables
- writing a conclusion which describes the type of mathematical relationship that exists between the variables.

Carry out an in-depth practical physics investigation involves:

- controlling the variable(s) that could have a significant effect on the results
- using technique(s) that increase the accuracy of the measured values of the dependent (and independent, if appropriate) variable
- writing a conclusion that describes the mathematical relationship obtained from the experimental data.

Carry out a comprehensive practical physics investigation involves writing a discussion that addresses critical issues such as:

- a reason why there is a limit to either end of the value chosen for the independent variable
- a justification for why a variable needs to be controlled
- a description of any difficulties encountered when making measurements and how these difficulties were overcome.
- the relationship between the findings and physics ideas
- a description of any unexpected results and a suggestion of how they could have been caused and/or the effect they had on the validity of the conclusion.

2 *A practical physics investigation* is an activity that includes gathering, processing and interpreting data.

Figure 1: NCEA Achievement Standard for a Level 2 practical Physics investigation.

Physics Level 3 Achievement Standard 90774

Carry out a practical physics investigation with guidance that leads to a mathematical relationship

Achievement Criteria

Achievement	**Achievement with Merit**	**Achievement with Excellence**
• Carry out a guided investigation that leads to a non-linear mathematical relationship.	• Carry out a guided investigation that reliably leads to a non-linear mathematical relationship.	• Carry out a guided investigation that reliably and validly leads to a non-linear mathematical relationship.

Explanatory Notes

1 The aim of the investigation will be given. The aim could be to find the mathematical relationship, or a physical quantity derived from the mathematical relationship.

2 *Guidance* means the teacher sets the parameters and provides general information. Students may be given background information relevant to the physics concepts and/or theory to enable them to discuss their results. The whole process is student driven.

3 For achievement, evidence will typically include:

- data relevant to the aim based on the manipulation of the independent variable and the consideration of other variable(s) that could affect the results
- uncertainties in raw data appropriate to the measurement
- a linear graph, including an error line, based on the data and relevant to the aim
- a conclusion that links to the aim and is drawn from information calculated from the linear graph.

4 For achievement with merit, evidence will typically include:

- accurate data relevant to the aim based on the manipulation of the independent variable over a reasonable range and number of values
- a description of the control of other variable(s) that could significantly affect the results
- the use of techniques to improve the accuracy of measurements
- appropriate uncertainties in raw and plotted data
- a linear graph with error bars and appropriate error line, based on sufficient data, relevant to the aim
- a conclusion that is relevant to the aim, based on the data, and is drawn from information calculated from the linear graph, including a processed uncertainty
- a discussion that evaluates the quality of the results.

5 For achievement with excellence, evidence will typically include:

- accurate data relevant to the aim based on the manipulation of the independent variable over a reasonable range and number of values
- a description of the control of other variable(s) that could significantly affect the results
- the use of techniques to improve the accuracy of measurements
- uncertainties appropriately calculated in all processed data
- a linear graph with error bars and appropriate error line, based on sufficient data, relevant to the aim
- a conclusion that is relevant to the aim, based on the data, and is drawn from information calculated from the linear graph, including processed uncertainty
- information calculated from the linear graph is correctly rounded
- a discussion that shows critical thinking, evaluates and explains the validity of the results, and considers relevant physics theory.

Figure 2: NCEA Achievement Standard for a Level 3 practical Physics investigation

Part 2: What the literature indicates about laboratory work in Physics

Several research papers are summarized in the Appendix. These synthesize the purposes of laboratory investigations and experimental work relevant to stage 1 Physics at the University of Auckland.
The criteria provided by each article is summarized below in the tables 7, 8 and 9 that match criteria to each laboratory exercise in use at this time.

Part 3: Analyzing the 2012 Laboratory Courses

The intended re-alignment of the Physics 120, Physics 150 and Physics 160 courses will require re-development of the laboratory courses since the shift of topics between courses will cause some of the experiments relevant to Physics 120 to be required in Physics 150 and vice-versa.
The Tables 3, 4 and 5 below provide the 2012 experiments and subsequent comments.

Physics 120: Physics of Energy

Expt #	Title	Objective	Description
1	Simple Pendulum	Measurement of local g-value, design of experiment, role and manipulation of errors	Students use the template of the expected lab report and the equation $T = 2\pi \sqrt{l/g}$ to devise their own method to measure l, T and g
2	Kinematics	Produce graphs of motion & understand relationship between different graphs of motion.	Students use a fan-cart to perform different motions and use a motion sensor to produce graphs of motion.
3	Projectile Motion	Investigate validity of the kinematics equations for projectile motion in the real environment.	Students measure time of flight and range and compare the ToF for different speed settings to see if they agree.
4	Laws of Cooling	Examine the rate of cooling of a brass object to see if it corresponds to forced cooling or natural cooling	Students measure temperature and time and use log-log analysis to find the gradient value and determine if it represents forced or natural cooling.
5	Speed of Sound in Air using Ultrasonic waves	To make an accurate measurement of the speed of sound in air	Students measure the frequency and wavelength of a sound wave at approximately 38-42 kHz and use phase matching to measure the wavelength and hence speed using $v = f\lambda$.

Table 3: 2012 experiments for Physics of Energy

Physics 150: Physics of Technology

Expt #	Title	Objective	Description
1	Measurement of Spring Constant	Measurement of spring constant from one of two methods.	Students choose one of two methods to measure spring constant, develop the plan and consider experimental issues.
2	Thin Lenses	Develop practical learning about lens properties and image formation; address misconceptions related to these lens properties.	Students make predictions then carry out several practical exercises to develop understanding about lens properties.
3	Young's Interference	Determination of wavelength of He-Ne laser from the interference pattern produced by shining the laser onto a double slit.	Students carry out prcaticals to determine the wavelength of the laser, slit separation and width of a human hair.
4	Charging a Capacitor	Explore charge and discharge of a capacitor to gain understanding of exponential decay.	Students carry out single charging and discharging and repetitive charging and discharging to explore these processes.
5	Measurement of e/m ratio	Study the deflection of cathode rays and measure the e/m of an electron.	Students use high voltage apparatus to measure the e/m ratio of the electron.

Table 4: 2012 experiments for Physics of Technology

Physics 160: Physics for the Life Sciences

Expt #	Title	Objective	Description
1	Speed of Sound	Measurement of the speed of sound in air, using ultrasonic waves.	Students measure the frequency and wavelength of a sound wave at approximately 38-42 kHz and use phase matching to measure the wavelength and hence speed using $v = f\lambda$.
2	Walking	Measure the waking speed of the human body and compare different ways of modelling walking motion.	Students measure oscillation of their leg, and their walking speed with strides, in-seam leg-length and effective leg-length. They choose the walking speed value for which the stride length is closest to leg length.
3	Resistance and Ohm's Law	Verification of Ohm's Law as example of resistance.	Students use a multi-meter to measure resistance and compare this idea to reduction of resistance to blood flow in leg by wearing compression socks.
4	Viscosity and Fluid Flow	Verification of Poiseuille's Law for viscous fluid flow.	Students gain understanding of viscosity and apply error techniques as they measure fluid flow and calculate viscosity then calculate Reynolds' number.

Table 5: 2012 experiments for Physics for the Life Sciences

The Tables 7, 8 and 9 below analyse each of the 2012 experiments in terms of the criteria discussed in the articles listed in Part 2: Literature Review

The definitions used in the analysis are listed in Table 6

Criterion	Students....
identification of variables	...are provided with background information and a relationship (when appropriate) and need to identify the independent, dependent and fixed variables to be investigated.
the manipulation of situations	... need to chose the most appropriate equipment and materials; make adjustments to the experimental situation so that uncertainty is minimised.
the building of mathematical models	... use data gathering and analysis techniques to draw graphs that show direct relationships and write a mathematical equation for the relationship (this may include uncertainties).
the evaluation of idealizations	....are required to identify assumptions and approximations they may use to develop the outcome sof the experiment.
Laboratory work serves conceptual knowledge	The laboratory work is used to increase the autonomy of students in their development of procedural knowledge and distinguishes between similar objectives such as verify, establish, discover and utilise.

Theory helps to understand practice	..need to understand why they chose a particular device to make measurements and that this apparatus is a theory made device. They acquire an intuitive insight into into the use of theory, the development of theoretical knowledge, the choice of data, the respective roles of measurement and observation.
Develops students' knowledge of the behavior of the natural world, helping them to make links between the world of natural phenomenon and the world of theoretical descriptions and explanation to develop understanding of scientific concepts.	... come to understand that values are not always exact and that uncertainties are always present. They are able to distinguish between 'accuracy' and 'precision'.
Develops students' understanding of how scientists undertake empirical investigations to address a question or problem of interest.	.... link the procedures of procedural knowledge to the ability to make hypotheses.
Developing students' ability to use standard laboratory instruments and procedures to carry out investigations.	... choose the most appropriate apparatus and the scale on that apparatus that provides the most appropriate values (these may be data with greatest accuracy) and use techniques to minimize uncertainties.
Assists students to develop high abilities at framing questions and designing experiments to answer them, at implementing their plans and analyzing their data.	...develop high abilities of framing questions and designing experiments to answer them.
Requires preparation by asking pre-lab questions	... receive experiments that include pre-laboratory exercises to set the context and encourage consideration of questions.
Provides counter-intuitive questions that students might check and true problems for students to solve.	... experiments include questions that need checking and receive true problems for students to solve.
Asks students for the invention of a measurement e.g. measuring gravity in three ways.	.... need to compare and evaluate the comparative values of a variable from at least two methods.
Reduces methodological detail so that students need to devise experimental design	... are provided only with an outline and need to develop their method so that it develops the relationship sought and minimises uncertainty.
Learning to use apparatus, to develop experimental techniques and skills.	...learn use equipment appropriately.
Experiment that enables students to develop a 'feel' for phenomena, to support assimilation of that phenomenon.	.....carry out their experiment and develop a greater understanding of the physics' phenomena to provide a more heuristic view of physics.
Uses project work, or investigations,	... carry out experimental work that requires greater initiative, independence and synthesis of understandings.
Practical that focus on some important physical quantity and encourage students to apply the operational definition of the quantity, to become familiar with typical values as 'benchmarks' and to measure the quantity. e.g. length, time, mass.	... carry out procedures to enhance understandings (correct misconceptions) of a particular phenomenon or quantity (e.g. behaviour of light when using lenses).
Skill-building mini-labs for estimating and processing uncertainties; making estimates and doing rough calculations; and giving a hierarchical goal-directed description of an experiment.	... carry out shorter practicals that are more structured and require students to carry out specific skill-building techniques.
Solving experimental problems	... are required to solve experimental problems such as estimating forces in a physical situation.
Requires students to process uncertainty associated with all data and encourages development of data summaries such as averages. e.g. error bars on graphs or standard deviations in tabulated data.	... recognize sources of uncertainty, apply strategies to reduce uncertainty, do not reject data without good reason, provide estimations of the total uncertainty.
Enables students to identify main sources of uncertainty	
Supports students to express degrees of confidence that can be placed on conclusions drawn from the data.	

Supports students to express conclusions that must be qualified and limited as appropriate to the sample used, the conditions under which tests were performed and for the range of measurements made.	... express the conclusions both qualitatively and quantitatively providing qualification of the limits of the experimental data (conditions and range).
Uses pre-lab requirements	As above
Uses post lab questions or test questions	...are required to answer quiz questions or written questions that seek to establish the understanding of each student about the experiment and/or limits of uncertainty.
Includes Problem Based Learning	... are required to consider a problem and fully design an investigation, taking into consideration and using all aspects of procedural knowledge.
Includes experiments with an engineering flavour.	...apply scientific, mathematical, economic, social, and practical knowledge, in order to design and build structures, machines, devices, systems, materials and processes.

Table 6: Definitions of terms related to physics procedural knowledge.

Physics 120: Physics of Energy

Article #	Criterion	Experiments that show this criterion				
		Pendulum	Kinematics	Projectiles	Cooling	Sound
1	identification of variables	1		3	4	5
1	the manipulation of situations	1				5
1	the building of mathematical models	1	2		4	
1	the evaluation of idealizations	1		3		
2	labwork serves conceptual knowledge	1	2	3	4	5
2	theory helps to understand practice	1	2	3	4	5
3	Develops students' knowledge of the behavior of the natural world, helping them to make links between the world of natural phenomenon and the world of theoretical descriptions and explanation to develop understanding of scientific concepts.	1	2	3	4	5
3	Develops students' understanding of how scientists undertake empirical investigations to address a question or problem of interest.	1			4	5
3	Developing students' ability to use standard laboratory instruments and procedures to carry out investigations.	1	2	3	4	5
4	Assists students to develop high abilities at framing questions and designing experiments to answer them, at implementing their plans and analyzing their data.					
4	Requires preparation by asking pre-lab questions	1	2	3	4	5
4	Provides counter-intuitive questions that students might check and true problems for students to solve.					
4	Asks students for the invention of a measurement e.g. measuring gravity in three ways.					
4	Reduces methodological detail so that students need to devise experimental design	1				5
5	Learning to use apparatus, to develop experimental techniques and skills.	1	2	3	4	5
5	Experiment that enables students to develop a 'feel' for phenomena, to support assimilation of that phenomenon.	1	2	3	4	5
5	Uses project work, or investigations,	1				
6	Practical that focus on some important physical quantity and encourage students to apply the operational definition of the quantity, to become familiar with typical values as 'benchmarks' and to measure the quantity. e.g. length, time, mass.	1		3		5
6	Skill-building mini-labs for estimating and processing uncertainties; making estimates and doing rough calculations; and giving a hierarchical goal-directed description of an experiment.					
6	Solving experimental problems	1		3		5
7	Requires students to process uncertainty associated with all data and encourages development of data summaries such as averages. e.g. error bars on graphs or standard deviations in tabulated data.	1		3	4	5
7	Enables students to identify main sources of uncertainty	1	2	3	4	5
7	Supports students to express degrees of confidence that can be placed on conclusions drawn from the data.	1	3		4	5
7	Supports students to express conclusions that must be qualified and limited as appropriate to the sample used, the conditions under which tests were performed and for the range of measurements made.	1		3	4	5
8&9	Uses pre-lab requirements	1	2	3	4	5
8&9	Uses post lab questions or test questions	1	2			5
10&11	Includes Problem Based Learning				4	
11	Includes experiments with an engineering flavour.					

Table 7: Analysis of Physics 120 experiments relative to literature review

Physics 150: Physics of Technology

Article #	Criterion	Experiments that show this criterion				
		Spring	Lenses	Interference	Capacitor	e/m
1	identification of variables	1		3	4	5
1	the manipulation of situations	1	2	3		
1	the building of mathematical models					
1	the evaluation of idealizations	1	2		4	
2	labwork serves conceptual knowledge	1	2	3	4	5
2	theory helps to understand practice	1	2	3	4	5
3	Develops students’ knowledge of the behavior of the natural world, helping them to make links between the world of natural phenomenon and the world of theoretical descriptions and explanation to develop understanding of scientific concepts.	1	2	3	4	5
3	Develops students’ understanding of how scientists undertake empirical investigations to address a question or problem of interest.	1				
3	Developing students’ ability to use standard laboratory instruments and procedures to carry out investigations.	1	2	3	4	5
4	Assists students to develop high abilities at framing questions and designing experiments to answer them, at implementing their plans and analyzing their data.	1				
4	Requires preparation by asking pre-lab questions	1	2	3	4	
4	Provides counter-intuitive questions that students might check and true problems for students to solve.		2			
4	Asks students for the invention of a measurement e.g. measuring gravity in three ways.					
4	Reduces methodological detail so that students need to devise experimental design	1				
5	Learning to use apparatus, to develop experimental techniques and skills.	1	2	3	4	5
5	Experiment that enables students to develop a ‘feel’ for phenomena, to support assimilation of that phenomenon.	1	2	3	4	5
5	Uses project work, or investigations,	1				
6	Practical that focus on some important physical quantity and encourage students to apply the operational definition of the quantity, to become familiar with typical values as ‘benchmarks’ and to measure the quantity. e.g. length, time, mass.	1	2	3	4	5
6	Skill-building mini-labs for estimating and processing uncertainties; making estimates and doing rough calculations; and giving a hierarchical goal-directed description of an experiment.		2			
6	Solving experimental problems	1		3	4	
7	Requires students to process uncertainty associated with all data and encourages development of data summaries such as averages. e.g. error bars on graphs or standard deviations in tabulated data.	1	2	3	4	5
7	Enables students to identify main sources of uncertainty	1		3	4	5
7	Supports students to express degrees of confidence that can be placed on conclusions drawn from the data.	1				
7	Supports students to express conclusions that must be qualified and limited as appropriate to the sample used, the conditions under which tests were performed and for the range of measurements made.			3		
8&9	Uses pre-lab requirements	1	2	3	4	5
8&9	Uses post lab questions or test questions/extension Qs			3		
10&11	Includes Problem Based Learning		2			
11	Includes experiments with an engineering flavour.					

Table 8: Analysis of Physics 150 experiments relative to literature review

Physics 160: Physics of Energy

Article #	Criterion	Experiments that show this criterion				
		Sound	Walking	Ohm	Viscosity	
1	identification of variables	1	2	3	4	
1	the manipulation of situations		2	3	4	
1	the building of mathematical models	1				
1	the evaluation of idealizations					
2	labwork serves conceptual knowledge	1	2	3	4	
2	theory helps to understand practice	1	2	3	4	
3	Develops students’ knowledge of the behavior of the natural world, helping them to make links between the world of natural phenomenon and the world of theoretical descriptions and explanation to develop understanding of scientific concepts.	1	2	3	4	
3	Develops students’ understanding of how scientists undertake empirical investigations to address a question or problem of interest.	1	2			
3	Developing students’ ability to use standard laboratory instruments and procedures to carry out investigations.	1	2	3	4	
4	Assists students to develop high abilities at framing questions and designing experiments to answer them, at implementing their plans and analyzing their data.				4	
4	Requires preparation by asking pre-lab questions	1	2	3	4	
4	Provides counter-intuitive questions that students might check and true problems for students to solve.					
4	Asks students for the invention of a measurement e.g. measuring gravity in three ways.		2			
4	Reduces methodological detail so that students need to devise experimental design					
5	Learning to use apparatus, to develop experimental techniques and skills.	1	2	3	4	
5	Experiment that enables students to develop a ‘feel’ for phenomena, to support assimilation of that phenomenon.	1	2	3	4	
5	Uses project work, or investigations,				4	
6	Practical that focus on some important physical quantity and encourage students to apply the operational definition of the quantity, to become familiar with typical values as ‘benchmarks’ and to measure the quantity. e.g. length, time, mass.	1	2	3		
6	Skill-building mini-labs for estimating and processing uncertainties; making estimates and doing rough calculations; and giving a hierarchical goal-directed description of an experiment.					
6	Solving experimental problems					
7	Requires students to process uncertainty associated with all data and encourages development of data summaries such as averages. e.g. error bars on graphs or standard deviations in tabulated data.	1	2	3	4	
7	Enables students to identify main sources of uncertainty	1	2	3		
7	Supports students to express degrees of confidence that can be placed on conclusions drawn from the data.	1	2	3	4	
7	Supports students to express conclusions that must be qualified and limited as appropriate to the sample used, the conditions under which tests were performed and for the range of measurements made.		2			
8&9	Uses pre-lab requirements		2	3	4	
8&9	Uses post lab questions or test questions					
10&11	Includes Problem Based Learning		2			

Table 9: Analysis of Physics 160 experiments relative to literature review

From this point onwards we need to consider

- How the learning process occurs;
- The responsibility that we have as assessors to scaffold their learning and achievements;
- The implications of the first two factors on the structure of the learning and assessment;
- Recommendations for the design of the assessment programme.

Part 4: The need to scaffold learning and determine development of procedural knowledge in the physics laboratory through formative and summative assessment.

Learning is made up of several aspects and needs careful structuring to ensure students know that they are given fair and supported opportunities to develop the knowledge and procedural skills of the Physics laboratory.

Students entering physics are now coming from a much wider set of backgrounds than, say, ten years ago. They enter having a wider variety of backgrounds from experiences in either NCEA or CSE, or from an overseas background. When entering first-year physics they may feel apprehensive and need some assurance about their ability to perform to the expected standards.

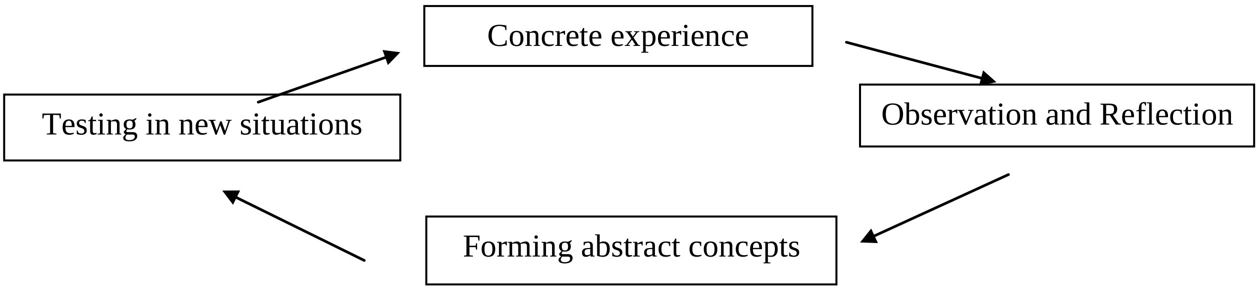
They need to have practice in developing the procedural knowledge and skills, with all their complexities, for physics. These aspects of physics procedural skills may be significantly different to the expectations of procedural knowledge in their concurrent biology, or chemistry, studies. On the other hand, the procedural knowledge development expected by teachers needs to be clearly signposted so that students can clearly see the sign-posts of development. Hence we need to consider the significance of *formative assessment* as compared to *summative assessment*.

Formative assessment

There are several potential uses of formative assessment:

- to facilitate learning through active student engagement to improve their learning and achievement;
- to see whether learning is taking place;
- to provide feedback to learners concerning their own progress, clarifying for the student what s/he needs to do to improve, extend or enhance learning through reflection and development;
- to provide feedback to teachers and laboratory demonstrator/assessors on how learners are progressing, clarifying for them what can be done to improve, extend or enhance the development of procedural knowledge and skills;
- to diagnose learners' needs or barriers to learning and help inform any necessary changes to the laboratory course.

David Kolb's ***Experiential Learning Cycle*** is very appropriate for considering development in the laboratory course:



In terms of this model, *formative assessment* can be seen as an example of **concrete experience,** and the process of feedback can be considered as **observation and reflection and forming abstract concepts** – the student must consider the feedback received and decide how to re-direct their efforts to improve.

When considering the need for formative assessment in the laboratory we can be reasonably sure that those students who have successfully completed the Level 3 NCEA Physics Investigation have developed a reasonable level of procedural knowledge about experimental design, control of variables, identification, minimisation and processing of uncertainties, developing a mathematical relationship between variables and writing a “discussion that shows critical thinking, evaluates and explains the validity of the results, and considers relevant physics theory.” These criteria were provided as part of the Level 3 Achievement Standard above. However, this may not apply to all students since they come from the wider perspective of backgrounds indicated above. Hence we need to find a balance between this expectation of prior-development and the need to provide a rigorous period of **concrete experience**. This shall be discussed further in the recommendations.

Part 5: Implications for the Summative Assessment Process.

Summative assessment

While formative assessment is *assessment for learning*, **summative assessment** is *assessment of learning.* Summative learning is normally carried out at the end of the course. It is always a formal process and it is used to see if students have acquired the skills, knowledge, behaviour or understanding that the procedural knowledge and skills have been acquired. Both the students and the teachers will be concerned with the results of the summative assessment.
The uses of summative assessment are:
- to record overall achievement;
- to anticipate future achievement;
- to allow students to progress to higher study after completing the requirements of the first-year laboratory so they are ready for the higher level analysis required.

What must be avoided is for students to view assessment as ‘meeting the requirements’ and not realizing the more holistic view of deepening their learning. Since the barrier between formative and summative assessment can be blurred if the distinction is not kept clear, then ways must be found to track a learner’s progress and then reward that progression. The dilemma of balance between formative and summative assessment can be achieved through the sense of tracking and leads to the student clearly understanding the purpose of the laboratory course and enjoying the reward of their efforts, while providing laboratory demonstrator/assessors the opportunity to provide encouragement and direction to the student to support that progression. One way of doing this will be discussed below.

Part 6: Heading towards the 2013 first-year physics laboratory programme

As indicated in the introduction to the research project, the re-arrangements proposed to the Physics 120 “Physics of Energy’ and Physics 150 “Physics of Technology’, together with the re-alignment of Physics 120 ‘Physics of Energy’ and Physics 160 ‘Physics for Life Science’ will have profound effects on the existing laboratory courses and leads to re-developments being essential.

Alignment of the Physics 120 and physics 160 courses will require:
Topics to be transferred from 120 to 150: Rotational Motion (12 lectures)
Topics to be transferred from 150 to 120: Electrostatics (9 lectures); Geometric Optics (3 lectures)
This will lead to the following topics and experiments given in Tables 10a, 10b, 10c, and 10d on these next four pages:

Note 1: that there are only five experiments listed in Physics 150 and one more is required.

Note 2:
It is intended to implement use of EXCEL for graph drawing in Semester 2 2012 for Physics 150

Physics 120	Physics 160	Physics 150
Mechanics (12 lectures) • Measurement, Conversions and Orders of magnitude. • Rectilinear Motion • Vectors • Two-dimensional Motion • Newton’s 2nd law • Newton’s 3rd Law • Static Equilibrium • Scaling – area, volumes etc. • Forces and their applications: contact, drag, lift and thrust. • Collisions – elastic, inelastic, explosive.	**Mechanics (12 lectures)** • Measurement, Conversions and Orders of magnitude. • Rectilinear Motion • Vectors • Two-dimensional Motion • Newton’s 2nd law • Newton’s 3rd Law • Static Equilibrium • Scaling – area, volumes etc. • Fluids: quantities, static fluids, continuity, Bernoulli’s equation, viscosity, Reynolds’s Number •Biomechanics: soft tissue, constitutive properties, equilibrium, lifting weights with upper arm, lower back and posture. Case studies.	**Mechanics** • Oscillatory Motion including SHM, damped SHM and Forced oscillations and resonance. • Rotational Motion : Rotational energy, moment of inertia, angular momentum, impulse, torque, rolling without slipping, Conservation of angular momentum. • Gravity, Kepler’s Laws, applications to current developments, precession.
2013 Experiments Kinematics Projectile Motion	**2013 Experiments** Viscosity Walking	**2013 Experiments** * Broken Pendulum

Table 10a: 2013 – Topics in Physics 120, Physics 160 and Physics 150

Thermal Physics (12 lectures) Temperature, thermal expansion, Ideal Gases, Ideal Gas scale, fixed triple point, Equipartiton of energy, degrees of freedom, molar heat capacities, Kinetic Theory, Heat and its transfer, vapour pressure, diffusion, thermodynamics, Work and PV diagrams, second law, heat engines and efficiencies, refrigerators, cyclic processes, reversible and irreversible processes, Carnot Cycle, Entropy	**Thermal Physics (12 lectures)** Temperature, thermal expansion, Ideal Gases, Equipartiton of energy, Kinetic Theory, Heat and its transfer, vapour pressure, diffusion, thermodynamics, Work and PV diagrams, second law, heat engines and efficiencies, reversible and irreversible processes, Carnot Cycle, Entropy	**Quantum Physics and Relativity** Quantum Effects, Quantum Theory, Atomic physics, Nuclear physics, Particle Physics, Relativity.
2013 Experiments Thermal Cooling OR * Thermal Efficiency & Heat Energy	**2013 Experiments** Thermal Cooling OR * Thermal Efficiency & Heat Energy	**2013 Experiments** Ratio e/m OR * GM Investigation of radioactive decay

Table 10b: 2013 – Topics in Physics 120, Physics 160 and Physics 150

Physics 120	**Physics 160**	**Physics 150**
Optics and Waves (12 lectures) • Basics – wave motion, physical and mathematical definitions. • Interference – stationary waves and resonance in organ pipes, frequency and modes of vibrations in strings, beats, shock waves. • Doppler effect for sound • Optics: light waves, em spectrum, and polarization. • Geometric optics • Photons • Acoustics • Wave equations for travelling wave. • Velocity of transverse wave on a stretched string. • Energy and power transported by travelling wave.	**Optics and Waves (12 lectures)** • Basics – wave motion, physical and mathematical definitions. • Interference – stationary waves and resonance in organ pipes, frequency and modes of vibrations in strings, beats, shock waves. • Doppler effect for sound • Optics: light waves, em spectrum, and polarization. • Geometric optics • Photons • Acoustics • Defects, correction. • Imaging – ultrasonic, attenuation, impedance, transducers, magnetic resonance imaging, precession, T1 and T2, Nuclear Physics in medicine.	**Optics and Waves (10 lectures)** • Wave Optics – Young's double slit, phase changes on reflection, interference in this films, single slit diffraction, the diffraction grating, X ray diffraction by crystals. • Polarisation
2013 Experiments Thin Lenses OR Investigation of relationship between Doppler frequency shift and rotational frequency.	**2013 Experiments** Speed of sound	**2013 Experiments** Young's Interference

Table 10c: 2013 – Topics in Physics 120, Physics 160 and Physics 150

Electricity (electrostatics) (9) • Charge conservation, Coulomb’s Law, electric fields, electrical shielding. • Potential difference, CRT, equi-potential surfaces, Millikan experiment. • Capacitance, dielectrics, electric field energy storage, applications of capacitors. • EMF, Batteries, current, resistivity, Ohm’s Law, Power, AC, DC, RMS and Peak voltage, temperature dependence of resistance, internal resistance. • Resistors in combinations. • RC circuits, time constants, Lenz’s Law. • Magnetism, electromagnetic induction, transformers	**Electricity (electrostatics) (9)** • Charge conservation, Coulomb’s Law, electric fields, electrical shielding. • Potential difference, CRT, equi-potential surfaces, Millikan experiment. • Capacitance, dielectrics, electric field energy storage, applications of capacitors. • EMF, Batteries, current, resistivity, Ohm’s Law, Power, AC, DC, RMS and Peak voltage, temperature dependence of resistance, internal resistance. • Resistors in combinations. • RC circuits, time constants, Lenz’s Law. • Magnetism, electromagnetic induction, transformers • Bio-electricity and propagation of electrical activation.	**Electrical Circuits and Magnetism (9)** • DC circuits: current and current density, voltage sources, Ohm’s Law, resistance, • Kirchhoff’s rules, simple two-loop circuits. • Magnetism: Definition of magnetic field, magnetic forces on currents and moving charges, Biot-Savart Law, magnetic materials, energy density of magnetic field. • Electromagnetic Induction: magnetic flux, Faraday’s and Lenz’s laws, inductance, eddy currents, generators and motors, the transformer, power transmission, LC and LCR circuits.
2013 Experiments Capacitor charge/discharge	**2013 Experiments** * Resistance and Ohm’s Law OR * Investigating efficiency and resistance of a DC Motor	**2013 Experiments** * Investigating efficiency and V-I characteristics of a geared DC Motor

Table 10d: 2013 – Topics in Physics 120, Physics 160 and Physics 150

Tables 11, 12 and 13 on the next page provide an overview of the changes required, with reasons.

Physics 120: Physics of Energy

	Simple Pendulum	Measurement of local g-value, design of experiment, role and manipulation of errors	***No longer valid as SHM is now in Physics 150***

Expt #	Title	Objective	Placement in 2013
1	Kinematics	Produce graphs of motion & understand relationship between different graphs of motion.	Physics 120
2	Projectile Motion	Investigate validity of the kinematics equations for projectile motion in the real environment.	Physics 120
3	Laws of Cooling ***OR*** Thermal Efficiency in Heat Engines and Heat Pumps	Examine the rate of cooling of a brass object to see if it corresponds to forced cooling or natural cooling	Physics 120 Physics 120
4	Speed of Sound in Air using Ultrasonic waves	To make an accurate measurement of the speed of sound in air	Physics 120
5	Charge and Discharge of Capacitor	Students carry out data gathering to analyse charge and discharge processes.	Physics 120
	Thin Lenses OR Investigation of relationship between Doppler frequency shift and rotational frequency	Practical exercise developing observations and skills for lens ray diagrams Investigation of mathematical relationship between Doppler frequency shift and rotational frequency.	***Possible substitution***

Table 11: 2013 experiments for Physics of Energy

Physics 150: Physics of Technology

Expt #	Title	Objective	Placement in 2013
	Measurement of Spring Constant	Measurement of spring constant from one of two methods.	***Not included in course***
	Thin Lenses	Develop practical learning about lens properties and image formation; address misconceptions related to these lens properties.	***Not included in course and possible to shift to Physics 120***
1	Broken Pendulum in SHM	Measurement of local g-value, design of investigation, role and manipulation of errors.	Physics 150
2	Investigating efficiency and V-I characteristics of geared DC Motor	Measurement of efficiency of lift vs mass of load and V-I characteristics of motor with generator effect.	Physics 150
3	Young’s Interference	Determination of wavelength of He-Ne laser from the interference pattern produced by shining the laser onto a double slit.	Physics 150
4	Experiment of characteristics of radioactive decay.		Physics 150
5	Measurement of e/m ratio	Study the deflection of cathode rays and measure the e/m of an electron.	Physics 150

Table 12: 2013 experiments for Physics of Technology

There are two experiments that are not consistent with the course since the shift of the topics from Physics 150 to Physics 120 removes the integration of these experiments with the lecture course.
- Measurement of spring constant
- Thin Lenses

Possible experiments to replace these include.

Broken Pendulum in SHM

Investigating efficiency and V-I characteristics of geared DC Motor

Experiment of characteristics of radioactive decay

Physics 160: Physics for the Life Sciences

Expt #	Title	Objective	Placement in 2013
1	Speed of Sound	Measurement of the speed of sound in air, using ultrasonic waves.	Physics 160
2	Walking	Measure the walking speed of the human body and compare different ways of modelling walking motion.	Physics 160
3	Resistance and Ohm's Law OR Investigating efficiency and V-I characteristics of geared DC Motor	Verification of Ohm's Law as example of resistance.	Physics 160
4	Viscosity and Fluid Flow	Verification of Poiseuille's Law for viscous fluid flow.	Physics 160

Table 13: 2013 experiments for Physics for the Life Sciences

Part 7: Proposals for 2013

Proposal 1. Using formative and summative assessments

The use of formative assessment in physics laboratory learning provides several opportunities:

- Students can be involved in the assessment process to maximise the effectiveness of the development of procedural knowledge. If students are not involved they will not perceive they are meeting the requirements while simultaneously deepening their learning.
- The assessors can provide clear directions to each student through descriptive feedback and thereby cognitively engage the student through comments and questions that need consideration. The descriptive feedback may provide both positive feedback to reinforce what they are learning well and provide the next-steps in the progression of developing procedural knowledge.
- Observations by laboratory demonstrators/assessors will go beyond walking around the room since the demonstrators will have opportunities to see that students are on-task, provide opportunities to ask questions, and to determine if any clarification is required.
- Questioning should be embedded in the laboratory work to allow for deeper thinking and insight into the detail of the procedural knowledge. Students' ability to ask better questions is another positive outcome.
- Formative assessment promotes student self-assessment and records keeping that result in more focused efforts to progress to higher levels of understanding the details of the development of procedural knowledge.

This proposal of formative assessment is already partly achieved through pre-laboratory exercises and follow-up questions, together with the brief written feedback that is provided. However these need expanding so that post-laboratory conferencing with laboratory demonstrator/tutors occurs and through additional detail included in training of laboratory assessors to ensure they understand the fuller range of implications of procedural knowledge relevant in physics. The issues and procedural knowledge listed in articles 2, 3 and 7 are particularly important. With these heightened expectations the laboratory demonstrator/assessors will be more effective in moving students' understanding of the laboratory component from a requirement to a perspective of development and essential knowledge that students will require in higher level physics.

Proposal 2: Tracking

One way to lead students towards the higher level of understanding of procedural knowledge, while providing a sense of development and achievement, is through tracking of achievement in each of the criteria and attitudes desired as the outcome of the practical course. The assessment record for each activity shows the criteria being assessed in the experiment, and provides both an achievement rating and written feedback. Each criterion is repeated at least once in other, later experiments, and the progression is noted both as a value and in terms of the written feedback. The student's final assessment value for that criterion is identified as the highest value scored in any achievement for that criterion. This requires both a feedback sheet attached after each experiment and a summary sheet for each student. However, this additional record keeping promotes students understanding of each criterion, supports them to know how to improve their achievement in that criterion, and so advance beyond the barrier of students developing the sense of 'meeting the requirements' to a real sense of meaningful progression in their procedural knowledge.

Proposal 3: Planned development towards project work

Another issue that has been raised in several of the articles, summarized above in Part 2, is the concern expressed about the need to avoid recipe style practicals and the need to involve students in genuine research style projects. There is also the need to balance the inclusion of project work with experiments that support the learning theory from lectures and the development of specific skills of measurement and manipulation. With only five experiments plus the introductory laboratory in each of the courses there are limited opportunities available for development of project work. Some of this balance may be achieved through using problem-solving activities as suggested in articles 5, 6 and 10 which may be part of a laboratory experiment session. However it is still important to implement the inclusion of project work as at least the last session so that an understanding of student development of procedural knowledge and skills is gained and so that students can see an end-point to the development process.

Further, it is suggested that the project work should be oriented towards the needs of students moving through the alternative physics pathway towards engineering. There is generally a large proportion of Physics 120 and Physics 150 students seeking entry into engineering through this alternative pathway. Article 11 provides several suggestions for such work that is given this bias.

Proposal 4: Changed orders of Experiments and Tutorials

To enable the most effective implementation of the laboratory course in 2013 it will be necessary to alter the order of the laboratory experiments. This will facilitate the use of some experiments as diagnostic exercises, the application of most experiments to promote development of procedural knowledge and the targeting of at least one experiment as a summative assessment.

Physics 120	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
	• Introduction • Errors • Problem Solving exercise	• Projectile Motion(P) • Kinematics (P) • Laws of Cooling **or** Efficiency of Heating & Heat Pumps (E)			• Charge and discharge of capacitor (P) • Thin Lenses (P) • **Speed of Sound in air (I**)	

Physics 160	Week 2	Week 3&4	Week 5&6	Week 7 & 8	Weeks 9&10	Weeks 11&12
	• Introduction • Errors • Problem Solving exercise	• Speed of sound (E) • Walking (E)		• **Investigating efficiency and V-I characteristics of geared DC Motor (I)** • Viscosity and fluid flow (E)		Exam Tutorials

Physics 150	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
	• Introduction • Errors • Problem Solving exercise	• Young's Experiment (E) • • Investigating efficiency and V-I characteristics of geared DC Motor (I)			• Measurement of e/m ratio (E) • **Broken Pendulum in SHM (I)**	

Proposal 5: Editing the Existing Experiments

After action-research observations made and meetings with the laboratory demonstrators, the need for several edits have been identified and reported.

Proposal 6: Introduction, Identification of objectives

Again it has been noticeable that many students are not aware of the objectives for the experiments. While they complete the experiments it is not convincing that they are improving their procedural knowledge at a significant rate. Therefore it is proposed that the pre-lab exercise should be enhanced with a short reading exercise and questions, and the requirement for students to identify the objectives and procedure before entering the laboratory.

Proposal 7: Order of experiments and experimental type

The above schedule includes practical exercises (P), experiments (E) and Investigations (I).
It is important that the last two experiments provide summative evidence. They must include at least one that is an investigation. This is identified in bold format. This will allow the students to experience the need to bring together all their experiences in an investigation they need to design and demonstrate their development of procedural knowledge. It will enable students to experience their satisfaction as they apply the aspects of procedural knowledge, practical problem solving and skills developed during the course.

Proposal 8: Inclusion of at least one EXCEL Computer workshop

The laboratory course begins with the essential development of the skills related to error identification and processing. The use of EXCEL for graph drawing may be included as one part of this initial session.

There is a need for at least one EXCEL computer workshop. This would have the objective of providing development of skills in using the equation editor, and analysing a practical problem using s spread-sheet e.g. terminal velocity of a sphere. If a second workshop was found desirable, the analysis of small angle approximations and trigonometric ratios might be considered.

Part 8: Issues and outcomes

The following issues were discussed with laboratory staff on 17th April 2012 at Curtin University.

Issues

1. Readiness of students for investigative work – what procedural knowledge and skills do the students bring? What variations are there? What influence might we have in secondary schools" to ensure readiness for Stage 1 Physics (advancing).
2. Balance of Physics and Engineering style experiments, inclusion of problem solving exercises.
3. Balance of practical exercises, experiments and investigations.
4. What information do we provide? Workshop material from Curtin.
5. How much information should we provide? Should we use more investigative style?
6. Assessment schedules for each type of involvement
   (Pre-lab 1; Overall outline 4; Analysis, uncertainties and Conclusion 5)
7. Formative and summative processes during course – need for feedback to students, how to do this most effectively and monitoring progress to ensure advancement.
8. Consistency of marking between laboratory demonstrators and expected /control of mark values.
9. Objectives of one semester and two semester courses and at least adequate preparation for Stage 2.
10. Time allocations for demonstrators (3 hours lab + 2 hours marking for 12-15 books.)

Summary of outcomes

1. Readiness of students for investigative work – what procedural knowledge and skills do the students bring? What variations are there? What influence might we have in secondary schools" to ensure readiness for Stage 1 Physics (advancing).

Student readiness is always varied with some having extensive experience of experimental work and investigations, while others have much less experience and development of procedural knowledge. Some students are only ready for recipe type experiments, and these are strongly criticised in the research literature, that expresses the need to implement authentic investigations. This depends on the school they came from and the courses offered there. It is important that schools need to be aware of the requirements and expectations of laboratory courses at each university and prepare students for those requirements. This implies that communication to secondary schools about laboratory course work is an important requirement.

2. Balance of Physics and Engineering style experiments, inclusion of problem solving exercises.

When courses offered include significant proportions of engineering students it is important to include experiments that include an emphasis of application and problem formulation and solving: thinking about equipment that might be used to address or explore a problem. At least one experiment with an engineering flavour might be offered in a course of five or six practicals.

Problem solving is valuable to develop problem solving ideas related to real-life physics situations. When students can develop the strategy to measure their take-off speed for a vertical jump, or find out how effective their sun-glasses might be to stop ultra-violet radiation entering their eyes, they gain the perspectives of both how Physics is related to real-life activities and how to apply theory to practice.

3. Balance of practical exercises, experiments and investigations.

It is necessary to confirm the differences between these.

Practical exercises are recipe type practicals in which students are provided the aims, variables and method and equipment and need to show a relationship or trend that is outlined in the introduction.
Experiments are practicals that provide the aim, and suggested variables but require students to develop the method, gather data and process it to develop the relationship between two variables, and write an analysis and conclusion.
Investigations provide a brief outline of the situation and pose a problem that requires solution and a required relationship. Students must devise the procedure independently and choose their preferred strategy, design the method, identify variables, solve any procedural problems and gather sufficient and appropriate data to develop the relationship analyse uncertainties and develop relationships that express uncertainties, explain limitations of the conclusions relative to their experimental situation and provide a valid conclusion.
Ideally there should be an introductory investigation to determine the initial procedural knowledge of the student, followed by only one or two practical exercises, at least one experiment, an engineering based experiment and a final investigation that determines the student’s progress through the course.

4. What information do we provide?

5. How much information should we provide? Should we use more investigative style?

In the pre-lab exercises students are required to consider the physical situation of the practical, provide reasons for certain features of the apparatus (e.g. why the angle between the plumb bob and the vertical is kept as zero during the projectile motion experiment), and to state how the variables will be manipulated to perform certain calculations. They may also be asked to show how uncertainties will be processed.

They should also need to read a brief outline of theory to focus their thinking and to identify the objectives for the practical.

The balance of experimental types is important, as outlined above.

6. Assessment schedules for each type of involvement.

There are at least two pathways for assessment.

a) Generalized criteria

Pre-lab 1; Overall outline 4; Analysis, uncertainties and Conclusion 5: Total = 10

This might be faster but is open to interpretation and considerable variation between assessors.

If this assessment method is used it is essential to have careful discussion about how to apply it and to provide practice assessments.

b) Criterion based assessment using detailed assessment. While this is more detailed and specific, it may not allow for the variety of practical types.

For both it may be necessary to use some method of moderation based on check marking of a sample of student work.

7. Formative and summative processes during course – need for feedback to students, how to do this most effectively and monitoring progress to ensure advancement.

There are at least two factors that contribute to enabling effective feedback and progress of student procedural knowledge and skills.

a) The design of the course that should include both diagnostic and formative assessment.

b) The critiques of the individual student's work with both quantitative and qualitative assessment. The latter includes specific comments directing the student to consider specific suggestions about how to improve their processing, analysis and conclusions.

8. Consistency of marking between laboratory demonstrators and expected /control of mark values.

This is a difficult issue that requires support and suggestions such as use of a marking schedule, initial marking in pencil and over-writing after comparison between students, marking by sections, comparison between partners. etc..

See # 6 above

9. Objectives of one semester and two semester courses and at least adequate preparation for Stage 2.

Lab course design needs to lead all students towards the expected initial level of a stage 2 student.

to do this the course needs to include pre-lab reading and questions, experiments and investigations, together with additional oral questions and quizzes that may be relevant in some experiments.

10. Time allocations for demonstrators (3 hours lab + 2 hours marking for 12-15 books.)

There seems to be general agreement in the consultation that demonstrator/assessors require equal time allocations within and after the practical sessions to adequately assess and provide effective, useful feedback.

11. Workshop material from Curtin University.

There seems to be an advantage for students if at least one or two computer-based workshops are provided. These enable students to develop data analysis and graphing skills in use of EXCEL, become familiar with the equation editor, and use it to examine trigonometric functions and analyse experimental situations such as the terminal velocity of a sphere.

Conclusion:

1) This report has provided research information that identifies criteria for procedural knowledge and matches it to the Physics 120, 150 and 160 courses' experiments. That enables identification that several aspects are not well developed by the current courses:

Criterion

- Assists students to develop high abilities at framing questions and designing experiments to answer them, at implementing their plans and analyzing their data.
- Provides counter-intuitive questions that students might check and true problems for students to solve.
- Asks students for the invention of a measurement e.g. measuring gravity in three ways.
- Reduces methodological detail so that students need to devise experimental design
- Uses project work, or investigations,
- Skill-building mini-labs for estimating and processing uncertainties; making estimates and doing rough calculations; and giving a hierarchical goal-directed description of an experiment.
- Includes Problem Based Learning
- Includes experiments with an engineering flavour.

2) Pre-lab exercises need to require brief reading of theory and identification of links to the experiment through both concepts and mathematical interpretations, together with the identification of experimental objectives.

3) In contrast to the more holistic assessment used up to 2012, tracking achievement in specific criteria would provide better feedback and would provide greater direction for development. Although the assessment criteria would be the same for all experiments, having specific assessment criteria will allow significant variations that allows identification of emphases to be considered by assessors in each experiment e.g. investigations will target explanations of variance between measured and accepted values, while practical exercises will only consider questions and diagrams.

3) There should be more consideration given to possible project work, investigations and technology-flavoured experiments. These need developing during 2012.

4) Consideration is needed for implementation of at least one computer-based workshop in Physics 120 and Physics 150.

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Reiner, M. and Gilbert, J.K. *The symbiotic roles of empirical experimentation and thought experimentation in the learning of physics.* International Journal of Science Education, December 2004 Downloaded from http://www.tandf.co.uk/journals on 21 April 2008

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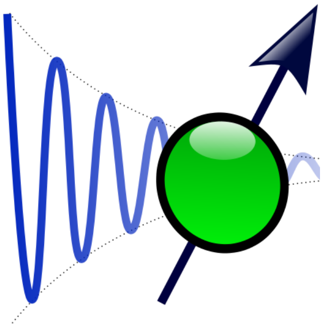

Appendix: Summary of research papers

Article 1:
The symbiotic roles of empirical experimentation and though experimentation in the learning of physics. IJSE 17 Dec 2004

Article 2:
Towards Renewed Research Questions from the Outcomes of the European Project '*Labwork in Science Education*'
Marie-Genevieve Sere 25 January 2002, Wiley Periodicals

Article 3:
Understanding of the Nature of Science and its Influence on Labwork
John Leach, University of Leeds, UK *Kluwer Academic Publishers*

Article 4: The link between the laboratory and learning
Richard T White, Faculty of Education, Monash University, Australia. IJSE
Downloaded on 21 April 2008 from http://www.tandfonline.com/doi/pdf/10.1080/0950069960180703

Article 5: The role of the laboratory in Physics Education
Woolnough, B.L. Department of Educational Studies, University of Oxford
Physics Education, Volume 14, 1979.

Article 6: Teaching physicists' thinking skills in the laboratory
Reif, F and St John, M, Physics Department, University of California, Berkeley.
American Journal of Physics, 47 (11), November 1979

Article 7: Is this the right answer?
Fairbrother., R, School of Education, King's College, University of London, UK
Hackling., M, Department of Science Education, Edith Cowan University, Western Australia.
International Journal of Science Education, 1997, Volume 19.

Article 8: The students' attitude and cognition change to a physics laboratory
Johnstone. A.H., Watt. A., and Zaman., T.U. Centre for Science Education, University of Glasgow, UK
Physics Education, 33(1) January 1998

Article 9: Enhanced student learning in the introductory physics laboratory
Cox, Anne.J., and Junkin, William F., Erkerd College, St Petersburg, Florida USA
Physics Education 37(1)

Article 10: Enhancement of First Year Physics with Problem-Based Learning Physics Labs

Antje Kohnle, Bruce Sinclair, Cameron Rae, Tom Brown. School of Physics and Astronomy downloaded from http://www.st-andrews.ac.uk/media/PBL_Physics1.pdf 18th December 2011

Article 11: Designing a new physics laboratory programme for first year engineering students

Kirkup, L., Johnson, S., Hazel, E., Cheary, R.W., Green, D.C., Swift, P., and Holliday, W.
University of Technology, Sydney, Australia
Physics Education, 33(4) July 1998

Article 1:
The symbiotic roles of empirical experimentation and though experimentation in the learning of physics. IJSE 17 Dec 2004

The study by Miriam Reiner and John Gilbert was an attempt to identify the epistemological roots of knowledge when students carry out hands-on experiments in physics. Several questions were investigated including:

· How important is it for students to actually do experiments in the laboratory?
· If it is important, what kind of experiments should they do?
· How does the fact that school experiments are not ‘owned by’ the students affect the development of divergent understanding of physics ideas, concepts and procedural knowledge?
· If thought experimentation is entailed in these processes, how best should we integrate historically important thought experiments into the curriculum as case studies of what they might do?
· How can computer-based learning environments, with their high capacity to facilitate thought experimentation, be best used to promote learning from physical experiments?
· How do we activate the ‘right’ learning processes in this symbiosis?
· What are the processes that lead to high quality learning in physics?

They found that, within the context of designing a solution to a stated problem, subjects constructed and ran ‘thought experiments’ intertwined within the processes of conducting physical experiments in a cyclic process in which mental pictorial constructs from the physical experiment are projected into a mental world of thought experiments and, in turn, applied to the physical experiment. . They showed that the process of alternating between these two modes - empirically experimenting and experimenting in thought - leads towards a convergence on scientifically acceptable concepts. This process was named “mutual projection”. In the process of mutual projection, external representations were generated. Objects in the physical environment were represented in an imaginary world and these representations were associated with processes in the physical world. It is through this coupling those constituents of both the imaginary world and the physical world gain meaning. Reiner and Gilbert further show that the external representations are rooted in sensory interaction and constitute a semi-symbolic pictorial communication system, a sort of primitive ‘language’, which is developed as the practical work continues. The constituents of this pictorial communication system are used in the thought experiments taking place in association with the empirical experimentation. The results of this study provide a model of physics learning during hands-on experimentation.

In the discussion they identify that:

· The importance of hands-on experiments is that "*they can be used to familiarize students with the reasoning processes related to innovation and discovery, such as the identification of variables, the manipulation of situations, the building of mathematical models, the evaluation of idealizations"* Additionally, they indicate *"hands-on experimentation is important because it involves the acquisition of sensory information about the phenomenon being investigated. Sensory patterns are memorized and re-used in new situations. .... This tacit knowledge is spontaneous and imaginistic in nature. Hands-on experiments in the physics laboratory provide a situation in which sensory patterns associated with physical phenomena can be experienced.*

· *The most beneficial experiments for learning are those that involve the students in sensory interactions, situated around an authentic problem, which grows out of students' motivation. Authentic, from this point of view, means that the learner has past experience related to the physics experiments, and that the learner finds it motivating to perform the experiment in order to solve a problem. Solving the problem needs to be significant beyond any local assessment requirements. The implication for designing learning environments is that both sensory and conceptual interaction needs to resonate with the learner's bodily and conceptual experience."*

Article 2:
Towards Renewed Research Questions from the Outcomes of the European Project *'Labwork in Science Education'*

Marie-Genevieve Sere 25 January 2002, Wiley Periodicals

A research project "Labwork in Science Education (LSE)" about labwork at upper-secondary and undergraduate levels was launched in 1996, funded by the European Commission. "*New research questions were presented, drawing upon the outcomes of the project. One was to present numerous potential objectives which can be aimed for in a laboratory. This means that conscious choices must be taken among objectives."* This paper studied these under the headings of

· conceptual objectives · epistemological objectives · procedural objectives

It is maintained that reality of labwork at upper-secondary and undergraduate levels is different from that at other levels, since students are required to manipulate truly complex theories and concepts. Students are expected :

· to *understand* theory as described in textbooks and lab sheets, or as explained during lectures;
· to *learn* concepts, models and laws;
· to *do* various experiments, using different pieces of theory and different procedures, in order to acquire a significant experience;
· to *learn to "do again"* the same experiments, and to follow the same procedures as utilized during preceding sessions;
· to *learn* processes and approaches and be able to apply and follow them in other contexts;
· to *learn* to use scientific knowledge, think with it, as experts do, and acquire the capacity to manage a complete investigation.

The benefits are not only in terms of "*to understand*" and "*to learn*", but also *"to do"* and "*to Learn to do".* However, Sere warns that the foremost identified problem was that embracing too many objectives in one session leads to failure. She proposes that targeted labwork with a limited number of objectives adapted to the situation are needed, but that the scope of these objectives needs to be widened.

The possible objectives of labwork are examined under the classifications of

· Conceptual – the theoretical knowledge used during labwork must not be considered as similar: verify, establish, discover, and utilize.
· Epistemological – when working with apparatus and objects, students acquire an intuitive insight into the use of theory, the development of theoretical knowledge, the choice of data, the respective roles of measurement and observation. In this sense, labwork is an opportunity for placing the philosophy of science in its proper context. However it would also be desirable to determine how the student's experience of labwork in the different science subjects causes convergence or divergence with the student's images of science.
· Procedural – What remains conscious, what is learnt as a process, and how an awareness of processes helps students to decide, plan, design and realize experiments on their own?

The paper elicits the following conclusions:

- The view of labwork serving conceptual knowledge exclusively must be balanced by the view that theory helps to understand practice. Students need to understand why a particular piece of apparatus is chosen and that a measurement device is a theory-made device;
- Labwork conceivers should consider that they need to put aside some traditional objectives, and to put emphasis on new ones.
- There should be importance given to procedures that promote student autonomy;
- Attention is needed to ensure progressive shaping of students' images of science;
- If student initiative is to be promoted then procedures need to be selected carefully;
- Specific conceptual knowledge is needed to understand the measuring instruments being used;
- Specific procedural knowledge is needed to choose a data analysis method.
- Research questions related to each type of classically recognized objective need to be devised so that they can be discussed by teachers and labwork tutors. Hence labwork tutors must be trained and aware of the target objectives of each session. They need to provide written feedback and guidance.

Article 3:
Understanding of the Nature of Science and its Influence on Labwork

John Leach, University of Leeds, UK *Kluwer Academic Publishers*

This study considers students' understanding of the nature of science and how this understanding influences their performance and understanding of labwork. It identifies three aims of labwork:

1. Developing students' knowledge of the behavior of the natural world, helping them to make links between the world of natural phenomenon and the world of theoretical descriptions and explanations to develop understanding of scientific concepts.
2. Developing students' understanding of how scientists undertake empirical investigations to address a question or problem of interest.
3. Developing students' ability to use standard laboratory instruments and procedures to carry out investigations.

The first aim is concerned primarily with teaching and learning content. The second and third are concerned with procedural knowledge.
They develop hypotheses about five aspects of procedural knowledge and suggest some relevant research questions.

1. **Hypotheses about students' images of data and measurement**.

1.1 Many students consider that, with good enough apparatus and enough care, it is possible to make a perfect measurement of a quantity and that such measurements are perfectly accurate.

Questions:

a) do students see measured data as a 'perfect copy of reality, or do they view measured data as being subject to uncertainty?
b) What do they see as the sources of uncertainty in measured data?
c) How do they overcome these uncertainties and select a value?
d) Do they recognize the difference between *accuracy* and *precision?*

1.2 Some students do not recognize the kinds of empirical evidence on which scientific knowledge claims are based. They think it is only possible to judge the quality of a measurement from knowledge of the true value, given by an authority source. They do not recognize that decisions about *precision* can be made from sets of measurements. Other students think it is possible to judge the quality of measured data from a set of repeated measurements and reason that data sets can be evaluated in their own terms to make decisions about accuracy and precision.

Questions

a) Do students believe that the only way to judge the quality of a measurement is from a known 'true' result?
b) Do they believe that the quality of a measurement can be judged from a set of repeated measurements?
c) Do they distinguish between the '*accuracy*' and '*precision'* of the measurements?

1.3 Many students see data reduction and presentation as a process of summarizing data and see heuristic processes of joining points on a graph, drawing a best-fit line, and drawing smooth curves as being independent of theory. They believe there are standard techniques for arriving at ‘perfect’ descriptions of data.

Questions:

a) When working with data sets, do students see procedures like joining data points with lines of best-fit or smooth curves as routine strategies used in sciences?

b) Do they see these procedures as a process of proposing tentative hypotheses?

2. Hypotheses about students’ images of the nature of investigation.

2.1 Some students think that logic of proof and falsification is symmetrical: data that logically support a law ‘prove’ the law, while data that does not support the law falsifies it.

Question:

Do students recognize the logical distinction between proof and falsification when handling empirical data?

2.2 Some students think that most/all questions about natural phenomena are answerable by collecting observational data and looking for correlations. Explanatory theories/models emerge from this data in a logical way; there is only one possible interpretation.

Questions:

a) Do students think that scientific theories emerge from data, or do they think of scientific theories and data as being related in a more complex way?

b) If so how are they related?

c) Might an experiment be open to more than one explanation?

3. **Hypothesis about students’ image of the nature of theory**

3.1 Some students believe that scientific theories are really descriptions of natural phenomena and that there is a one-to-one correspondence between theory and reality. Such students believe that it is a straightforward empirical process to show that scientific theories are true. Others believe that theories are model-like and do not simply describe reality.

Question:

Do students think that scientific theories are conjectural and model-like in nature, or do they think that theories are simply descriptions of phenomena in different terms?

4. Hypothesis about students’ images of the nature of explanation.

4.1 Some students do not recognize the different levels, types and purposes of explanation that are used in science (teleological, causal, descriptive, model-based: Tomar & Zohar 1991)

Question:

Are students able to distinguish between teleological, descriptive and model-based explanations of natural phenomena?

Article 4: The link between the laboratory and learning
Richard T White, Faculty of Education, Monash University, Australia. IJSE
Downloaded on 21 April 2008 from http://www.tandfonline.com/doi/pdf/10.1080/0950069960180703

White begins by providing an indication that research shows disappointing results and conclusions about the intentions and purposes of laboratory work. He then describes that the laboratory is the only means of achieving some purposes, while for other purposes the laboratory is only one among several means. His research indicates a wide range of opinions about the purpose of laboratory work. These purposes include the need to develop manual dexterity, fine movements, precision and care; to encourage social skills such as co-operation; and the acquisition of specific techniques. He describes Woolnough's (1983) argument that the real uses of the laboratory are to develop skills, to teach how to work as a scientist, and to acquire a feel for phenomena, while questioning the belief that it supports understanding. White also discusses the research by Lynch and Ndyetabura (1983). They surveyed varying views of science teachers and students and found that aims to do with making theory more understandable were highly rated, while preparation for examinations were lowest rated. Finally White describes that Denny and Chennell (1986) found that students see the over-riding purpose as learning with understanding, including helping to remember, developing interest, and developing a sense of achievement and responsibility.

White continues by discussing the “Methods of science', indicating that procedural knowledge in science is much more complex and varied than carrying out an experiment in which we identify fixed variables and variation of one other variable. He quotes work by Woolnough (1991), Watson (1970) and Gunstone and White (1981) and asserts that laboratory work is over-determined and rigid, with emphasis on getting the one expected answer by one and only one appropriate method. Rather, laboratory work should contribute to each student's:
1) Meaning: ‘Episodes' should be one of the main outcomes of labwork. Episodes are *recollections of events in which the person took part or at least observed.* They *must be memorable and must be associated by the learner with the knowledge they support* to provide better understanding through linking of experiments performed to propositions, or to ask questions after each laboratory exercise about which proposition/s it illustrates.
2) Motivation to learn: In fact, the studies quoted by White give mixed results, with positive, neutral and negative effects all being indicated.
Finally White makes suggestions for effective laboratories:
1) While direction-following experiments should be avoided, implementation by Roth (1994) of problem-solving in physics laboratory work resulted in students developing high abilities at framing questions and designing experiments to answer them, at implementing their plans and analyzing their data.
2) Watts (1994) and Walker (1975) provide good suggestions such as counter-intuitive events that students might check and true problems for students to solve.
3) Invention of a measurement e.g. measuring gravity in three ways.
4) Adding to the reality of the investigation by using larger scale, outdoor experiments e.g. size of centripetal acceleration.
5) Reduction of methodological detail so that students need to devise experimental design.
6) Requiring preparation by applying pre-lab questions.

Article 5: The role of the laboratory in Physics Education

Woolnough, B.L. Department of Educational Studies, University of Oxford
Physics Education, Volume 14, 1979.

This conference report emphasizes how essential it is to have congruence between the aims of the laboratory course and what was actually done in the course by the students. It also reports the enthusiasm and commitment shown by attendees for the value of investigational project work and the issues relating to it. Finally it also emphasizes the widespread disenchantment with practical work that simply provides a list of instructions for students to follow.

The conference identified three types of practical work. Firstly learning to use apparatus, to develop experimental techniques and skills. Secondly, experiments that enable students to develop a ‘feel’ for phenomena, to support assimilation of that phenomenon. Finally, the use of project work, or investigations, to give the holistic sense of physics in practical work.

Article 6: Teaching physicists' thinking skills in the laboratory

Reif, F and St John, M, Physics Department, University of California, Berkeley.
American Journal of Physics, 47 (11), November 1979

This article describes an effort to improve laboratory instruction by examining the basic goals, its teaching methods, and its implementation through specific experiments. Concurrent to this was the objectives of improving students' thinking skills and attitude about physics. They develop a prototype introductory physics laboratory designed to teach students some general intellectual skills widely useful in scientific work. These skills include basic skills (such as estimating quantities, determining errors and applying useful measuring techniques) and higher-level skills (such as effectively describing experiments and flexibly adapting then resulting knowledge to different conditions). The teaching methods emphasize the utility of organizing information in hierarchical and goal related ways.

The use of mini-labs is suggested to devise a way to have optimum application and effect towards the objectives of the laboratory course and since these intellectual skills are often not acquired by students in more traditional courses. The minilabs are seen to have advantages including:
1) each minilab concentrates on only a few relatively simple skills which a student can readily master.
2) since each minilab is relatively brief, students are able to work on a greater variety of simple experiments. This allows use of audio-visual and enables more expensive equipment to be used since fewer of these more expensive items are needed.
At the end of each minilab, there is a self-test which students can use to assess their mastery of the capabilities which they should have learned. These can be either short, written tests or mutual tests utilizing a more game-like approach. Finally, after all minilabs are completed, students attend an interview which includes questions and student explanations. Strengths and weaknesses of the student's performance are discussed and grade assigned.

The minilabs present the goal of the experiment as a problem to be solved, provides an overview of the main theoretical principles, with some elaboration, but avoiding a set of laboratory instructions. The information focuses on the central issues and leaves the student to work out details. Students fill in details in blank spaces and ask for estimates of the value of then variable to be measured. The preparation is done by the student before they enter the laboratory and is checked by the supervisor. Flow charts are used to encourage students to use high-level, distraction-free organizational plans of the experimental procedure. The instruction materials are designed to scaffold students becoming independent researchers.

The minilabs are of three types:
1) Practical that focus on some important physical quantity and encourage students to apply the operational definition of the quantity, to become familiar with typical values as 'benchmarks' and to measure the quantity. e.g. length, time, mass.
2) Skill-building mini-labs for estimating and processing uncertainties; making estimates and doing rough calculations; and giving a hierarchical goal-directed description of an experiment.
3) Solving experimental problems such as estimating the force exerted by a person's legs, or the power delivered when riding a bicycle, or forces involved in car crashes.
Other longer experiments included measuring the gravitational acceleration by observing the bounce of a super-ball on the floor; using several methods to predict and verify the range of a projectile.

Article 7: Is this the right answer?
Fairbrother., R, School of Education, King's College, University of London, UK
Hackling., M, Department of Science Education, Edith Cowan University, Western Australia.
International Journal of Science Education, 1997, Volume 19.

Many experiments performed by students require them 'to get the right answer'. This article examines this issue and examines how students and teachers use fraudulent data or over-simplification and assumptions that students make to cause them to falsify data and outcomes. It suggests looking both inwards at the nature of the subject, and looking outwards at the pressures to devise ways to overcome these difficulties. This summary will examine only what we can do about it since this provides the most useful information.

The authors indicate that we must understand the nature of the problem and why it exists, together with the internal matters of understanding about the Nature of Science and what is 'good practice; and the external matter of how examination pressure affect what happens in labwork.

Internal Issues:
It is essential that teachers, laboratory staff and students all have '*an understanding about the nature of science and what is involved in doing science'.* The authors remind us that, as we require labwork to be an essential part of their science experience, we simultaneously require students to use their expertise, knowledge and understanding to problem solve, while also requiring them to be learners. These two have quite conflicting attitudes and behaviors. This is particularly difficult for students early in their development of science learning when they are not fully independent learners. As researchers, students are expected to develop and show integrity, willingness to be scrutinized and questioned about other conflicting results, understanding about the need to have repeatable results, and producing congruent results through other methods. They need to be able to identify and discuss uncertainties and the methods they used to minimize those uncertainties. These skills and procedural knowledge enables students to avoid regarding experiments having only the right, or wrong, answer. An effective experiment is one in which all the '*parts fit together, it functions and gives an answer that can be defended.'*

Fairbrother and Hackling provide a very extensive summary of specific skills and processes which should be an essential part of the teaching of procedural knowledge and suggest that these can only be achieved through a program that develops them over a period of time. Refer to Figure 3 on the next page.

External Issues:
Since investigations are only a relatively small part of science it is necessary to decide where the balance lies between incorporating investigations as the 'new science', and providing old-science experiments that are more structured but still useful. This balance must be decided on the assessors of the whole course and will reflect the chosen balance between content knowledge and procedural knowledge. Tamir (1993) reminds us of two reasons why testing acts as a barrier to innovation:
1) Innovations that compete with test are more likely to fail.
2) '*Tests that do not match the innovation fail to reveal the impact of the innovation'*.
The authors suggest that it is essential that the assessment properly reflects the objectives of the education, both in emphasis and coverage.

Finally, the authors discuss how the nature of science teachers affects the assessment of practical work. They quote Marshall (1995) who maintains that Science teachers lack confidence in making judgments about students' work (compared to teachers of English). Marshall believes that English teachers are brought up to value diversity and that there is more than one-way to being right. Science teachers are brought up to believe that evidence leads to an incontrovertible conclusion. "*Opinion, subjectivity and ambiguity are apparently values less although they are common*" in science.

1	There is a degree of uncertainty associated with all data.	
2.	There are three main sources of uncertainty	· poor measurement techniques · poor control of variables · small and/or unrepresentative samples
3.	The degree of uncertainty can be reduced by	· trialing and refining the measurement procedure · being careful and consistent with the measurement procedure; · using repeat trials to reveal magnitude or random measurement error; · using repeat trials with averaging to increase sample space; · using more than one measure of the phenomenon and triangulating data; · using a design for the experiment that keeps constant as many variables as possible; · using randomization of subjects or samples to reduce the effect of interfering variables that cannot be kept fixed. · maximizing sample size and use sampling procedures that enhance representativeness. · using replication to increase sample space and provide a check on control of variables and sampling error.
4.	No data should be discarded without careful and objective justification e.g. use repeated measurements to show that the reading is alone in being considerably beyond the normal range of measurements and there is a plausible explanation for the outlying reading in terms of procedural error.	
5.	Some indication of uncertainty should be included with data summaries such as averages. E.g. error bars on graphs or standard deviations in tabulated data.	
6.	As a consequence of uncertainty in data there must be degrees of confidence that can be placed on conclusions drawn from the data.	
7.	Conclusions must be qualified and limited as appropriate to the sample used, the conditions under which tests were performed and for the range of measurements made.	

Figure 3: Specific Skills and Processes suggested by Fairbrother and Hackling

Article 8: The students' attitude and cognition change to a physics laboratory
Johnstone. A.H., Watt. A., and Zaman., T.U. Centre for Science Education, University of Glasgow, UK
Physics Education, 33(1) January 1998

The authors carried out a study of the students' responses to an attitude questionnaire that had been checked for reliability. The results of this study were supported by statistical evidence. The responses "*tend to confirm that pre-lab fostered a positive attitude in students towards the changes made in the physics laboratory*." With pre-lab students understanding of physics practical work improved and there was a large improvement in the post-lab work.

Article 9: Enhanced student learning in the introductory physics laboratory
Cox, Anne.J., and Junkin, William F., Erkerd College, St Petersburg, Florida USA
Physics Education 37(1)

Laboratory experiments were modified to include aspects of peer instruction and collaborative learning. Students were required to answer multiple-choice questions as they progressed through their experiments. These experiments were predictive, observational, or explanatory and represent a modification of Edward Mazur's Peer Instruction transferred to the laboratory.

Pre-lab and post-lab tests were used to measure student learning gains in two of the labs. Modifications included conceptual questions that students answered on-line and then discussed with other groups. By comparing student performance on pre- and post-tests in two laboratories that used this technique and two that did not use this technique, data indicates that this modification substantially increases student learning by 50-100%. "*It seems that using labs with these modifications increases student readiness to communicate and their ability to transfer knowledge or apply concepts to novel situations."*

Article 10: Enhancement of First Year Physics with Problem-Based Learning Physics Labs

Antje Kohnle, Bruce Sinclair, Cameron Rae, Tom Brown. School of Physics and Astronomy
downloaded from http://www.st-andrews.ac.uk/media/PBL_Physics1.pdf 18th December 2011

The aim of the project was to include problem-based learning (PBL) lab work in the second semester of the first year physics laboratory. Students were given a problem in groups of three to four requiring the measurement of the wavelength-dependent transmission of sunglasses. The scenario involved students working in a firm producing sunglasses and checking claims of a rival firm that their sunglasses block virtually 100% of UV and high-energy visible light. Student groups needed to come up with their own experiment, request the relevant apparatus, carry out the experiment, and analyse the results.. There was substantial variation in experiment design by the students: setups included a dual-band UV lamp, a mercury lamp with diffraction grating, a prism spectrometer and a white light source with diffraction grating and with colour filters. At the end of the lab afternoon, students were shown a spectrophotometer in one of our research labs, and were shown how this measurement would be done in a professional research environment.

An evaluation in the form of a questionnaire at the end of the lab afternoon showed that most students preferred this type of lab to "traditional" labs (mean of 2.1 on a scale of 1 to 5, with 1 being highest preference, 44 responses, ~80% of the class), found the team work (mean 1.8) and the research lab visit (mean 2.1) useful, and would wish for more labs of this type (mean 2.2). Students had the possibility to come up with their own experiment and thus apply the lab skills they had learned in the more traditional labs. They also saw how the same problem would be solved in a real research environment. Though the students were not doing real research, they were working in "research mode", i.e., having to decide themselves what they needed to measure, how they would go about doing this and how to analyse and represent their data.

The aim was to enhance the student experience by increased engagement, deeper learning, enhancement of problem-solving skills, laboratory skills and social skills and an enhancement of student motivation.

Article 11: Designing a new physics laboratory programme for first year engineering students

Kirkup, L., Johnson, S., Hazel, E., Cheary, R.W., Green, D.C., Swift, P., and Holliday, W.
University of Technology, Sydney, Australia
Physics Education, 33(4) July 1998

A new physics laboratory programme for first-year engineering students was devised and sought to provide balance between specific technical competencies and more open activities. Discussion between stakeholder groups revealed that many of the goals for fist-year physics laboratory work for science students are congruent to those for first-year engineering students.

The programme included experiments with an engineering flavour, or bias, though no experiment was given an engineering 'method' as focus. The new laboratory programme provided:

- experiments with an engineering flavour;
- compulsory pre-work accompanying each laboratory session, to orient students to the upcoming experiment and provide useful background information;
- time for students to devise their own experimental procedures;
- opportunities to describe their methods and results to the whole class in a semi-formal manner;
- experiments linked to, and sequenced with, material delivered in lectures;
- larger units of work, each spanning more than one week;
- all students performing the same experiment within the same week, replacing the old programme's 'circus' of experiments.
- a diverse range of assessment instruments.

Examples of experiments included two projects on Thermoelectric cooling:

Project 1

A soft drinks manufacturer wants to keep their product 'Spring Water' at a temperature of 4 °C without the use of a conventional refrigerator and has opted to use one (or more) TEC(s) for cooling. Your task is devise, build and test a system using one TEC (for groups working in pairs) or two TECs (for groups of four) that will keep as much water as possible at a temperature of 4 °C.

Project 2

A company has just created a new alloy with unusual electrical and optical properties. It is important to specify these properties over as wide arrange of temperature as possible. The investigation demands that cooling occurs without vibration, thereby eliminating conventional cooling methods which use compressors. Your task is to devise, build and test a system using one TEC (for groups working in pairs) or two TECs (for groups of four) that will cool a specimen of the alloy to as low a temperature as possible.

"*The open-ended nature of the experiment encouraged students to take diverse approaches to their projects. While some focused upon minimizing the transference of heat to the water/alloy, others confronted the issue of how much thermal energy was removed from the water/alloy for a given amount of energy delivered to the TEC. A range of materials were available to all the students at a central point in the laboratory. ...Students were encouraged to choose a combination of materials they thought suitable for their experiment.*"