Physics III Laboratory Module at the University of the Witwatersrand

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Abstract. One of the problems facing experimental physicists at the University of the Witwatersrand is the small number of home-grown graduate students opting for experimental physics projects when deciding to pursue higher degrees in the School of Physics. It has been suggested that the reason for this may lie in the structure and curriculum of the undergraduate laboratory courses. The curriculum for the Physics III Laboratory module at the University of the Witwatersrand is well-established, and has followed a particular format for approximately a decade. A new module co-ordinator was appointed at the beginning of 2011, and it was decided to review the curriculum, and actively make changes if this was required. Accordingly, a comprehensive student survey was presented to the student cohort towards the end of 2011. The results of the survey highlighted several issues which have the potential to make experimental physics unattractive. During 2012 several changes were made to the course in response to the survey, and their efficacy is at present being monitored carefully. Results of the survey and details of the measures taken to address some of the student concerns will be presented.

1. Introduction

The experimental component of an undergraduate Physics Major curriculum should ideally introduce the student to Experimental Physics as an integral part of the subject, and students should be made aware of the vital role that Experimental Physics plays in the development of the discipline. During the last ten years it has become increasingly clear that the Physics Major curriculum may not be achieving one of its secondary goals – that of providing the School of Physics at the University of the Witwatersrand (WITS) with a cohort of enthusiastic and motivated graduate students opting for experimental projects. The reasons for this are not immediately clear, and the matter has been discussed informally in various forums. It has been suggested that students are “turned off” Experimental Physics by the present curriculum, and this paper reports on the first steps in an ongoing critical assessment of the present state of the curriculum.

The development of curricula for high school and first year experimental physics courses has received a great deal of attention from specialists in Physics Education. A review of the literature shows, however, that little substantive work has been reported on senior laboratory courses, or on the development of a coherent laboratory curriculum for a Physics Major stream.

The 3rd Year Physics course at WITS is made up of five modules. They are Quantum Mechanics III (PHYS3000), Applications of Quantum, Mechanics III (PHYS3001), Statistical Physics (PHYS3002), Waves and Modern Optics III (PHYS3003), and Advanced Experimental Physics and Project III (PHYS3006). In terms of calculating the final mark for the course, the laboratory module (PHYS3006) is worth 28 points and the other four (theory-based) modules are worth 11 points each.

2. The PHYS3006 Module

The PHYS3006 module consists of four broad areas of activity. Each of these areas of activity are discussed in this section.

2.1. Set Experiments (30 % of the final mark for the module)

Eight Set Experiments are offered, and each student will do five of these experiments during the course of one teaching quarter. Students do the experiments as individuals, and are assisted by a demonstrator assigned to the experiment. Students are supplied with a handout giving the details of each experiment (handouts to all set experiments are distributed at the start of the relevant teaching quarter), and take the experimental data during the course of one afternoon. Laboratory reports are due one week after the experiment, and the students are required to make use of the library, on-line resources, data-fitting packages and a word processing package to produce the final laboratory report. The reports are typically between eight and fifteen pages long, depending on the experiment. The students are supplied with a rubric, which gives details of the marks allocated to each section of a typical laboratory report. The demonstrator responsible for the experiment marks the completed report.

2.1.1. *Michelson Laser Interferometer.* The objective of this experiment is to introduce students to the principle of interferometery and its application to relative displacement measurement. The experiment is done on a high quality optical table.

2.1.2. *Optical Diffraction.* The experiment introduces the student to advanced optical spectroscopy, including Fourier transforms. The relationship between optical spectroscopy and electron and X-ray spectroscopy is emphasized.

2.1.3. *Temperature dependence of the resistance of a metal and a semi-conductor.* Students investigate the temperature dependence of the resistance of the two samples in the temperature range 100 K – 300 K. Elementary band structure concepts are introduced through analysis of the experimental data, and are required to calibrate a thermocouple.

2.1.4. *Magnetic Resonance.* Students measure the g-factor of the proton and the electron using continuous wave nuclear magnetic resonance and electron paramagnetic resonance respectively. The natural line-width of the resonance lines is emphasized.

2.1.5. *Lecher Wires.* This experiment introduces students to the transmission of electromagnetic waves along transmission lines. They obtain the velocity of the waves and examine the properties of the transmission lines, and examine the properties of a standing electromagnetic wave.

2.1.6. *X-ray Spectroscopy.* Students are introduced to X-rays, and a calcite crystal is used to investigate the X-ray spectrum produced by a copper tube in a research-quality diffractometer. This is followed up by a study of some powder samples using the K_α copper line.

2.1.7. *γ-ray Spectroscopy.* The objective of this experiment is to introduce the student to some of the techniques used in nuclear physics data capture, while providing an introduction to basic nuclear physics. A modern computer-based Multi Channel Analyzer is used to capture γ-ray spectra, and analysis is done using computer-based data fitting packages.

2.1.8. *Radio Astronomy.* Students make use of equipment based on the principles of Radio Astronomy to study the microwave spectrum of the sun. A simple arrangement involving standard satellite receiver dishes is used.

2.2. Electronics Experiments (20 % of the final mark for the module)

Students are introduced to electronics during the 2nd Year, and this part of the PHYS3006 module is an extension of the 2nd Year course to transistors and digital electronics. In total five experiments are completed involving a number of circuits. Two demonstrators are assigned to the electronics experiments, the students work individually, and part of the mark assigned to each experiment is based on an in-lab assessment of the circuits built.

2.2.1. *Introduction to Electronics.* This experiment is designed to introduce the students to the experimental apparatus (which differs noticeably from the equipment used in the 2nd Year). Potential divider, and low and high pass filters circuits are constructed and tested.

2.2.2. *Transistors.* The use of transistors in amplifier circuits is presented. The students build and test four circuits involving transistors, including an audio amplifier.

2.2.3. *Introduction to Digital Electronics.* Students are introduced to building TTL logic circuits using diodes. Three diode logic circuits are built and tested, including a cascaded OR and AND configuration.

2.2.4. *Gates and Flip-Flops.* Integrated circuits are introduced in this series of four circuits. The use of gates and flip-flops in real devices is emphasized.

2.2.5. *Counters, Encoder and Decoder.* Two circuits are built and tested in this experiment. These are a Programmable Divide-by-N Counter and a Binary Encoder. Details of a possible decoder circuit are also provided.

2.3. Specialist Lectures and Essays (10 % of the final mark for the module)

During the 3rd and 4th quarter two afternoons are devoted to lectures that are presented by research specialists. In 2011, for example, lectures were presented on Experimental Nuclear Physics and Superconductivity. The lectures included an introduction to the relevant fundamental concepts, and to recent research results and the experimental techniques employed. Students were required to listen, take notes and then write an essay of not less than two pages on the lecture. This exercise is designed to enhance the critical listening and writing skills of the students.

2.4. Major Project (40 % of the final mark for the module)

The major project is done during one teaching quarter. The aim of the project is to introduce the student to the research interests of the School of Physics, but they are didactic rather than research-based. The projects may be exclusively experimental, computational or theoretical in nature, or may be a combination of two or more. Projects are offered by research-active staff of the School and associated entities. Projects are intended to develop the following attributes that are necessary for a young scientist: critical reading of the literature; analytical, experimental, computational and theoretical skills (depending on the focus of the project); written and oral communication skills.

2.4.1. *Choice of a Project.* Students are required to approach at least three potential supervisors before making a final choice of project. A list of potential supervisors and their contact details is provided, and students are encouraged to find out the research interests of the staff by using web resources.

2.4.2. *Quality Control.* During the third week of the relevant teaching the course co-ordinator meets with each of the students who are busy with their project. During this meeting the course co-ordinator ensures that the supervisor and the student have a decent working relationship, that the project is proceeding within the time constraints, and that the student has a reasonable idea of what they are required to do.

2.4.3. *Project Report.* The students submit a written project report in the first week of the teaching quarter following the quarter in which they completed the project. The report should follow the layout of a long scientific paper, and they are usually between twenty and forty pages long. The supervisor marks the report following suggested guidelines. The report counts 25 % of the final module mark.

2.4.4. *Oral Presentation.* During the final teaching quarter several afternoons are set aside for oral project presentations. All members of staff are invited to the presentations, and each staff member allocates a mark to the presentation based on the quality of the presentation, familiarity with the work they are presenting, and the student's response to questions posed by the audience. A discussion of the projects by staff members follows, and the final mark for the oral presentation is an average of the marks submitted by the staff members present. The oral counts 15 % of the final module mark.

3. Student Assessment Survey conducted at the end of 2011

The PHYS3006 module has been run along the lines outlined in Section 2 for a number of years. During 2010 I was appointed to co-ordinate the course, effective from the beginning of 2011. Mindful of the desire to evaluate and modify the laboratory curriculum for the Major stream, I administered an official University Student Assessment Survey towards the end of my first year as co-ordinator (September 2011). The survey consisted of 24 multiple response assertions based on a standard Strongly Agree (10), Agree (7.5), Neutral (5), and Disagree (2.5), Strongly Disagree (0) scoring method. In addition, there were three open-ended questions as follows:

- Which aspects of the course were most valuable?
- Which aspects of the course were least valuable?
- Any suggestions about how to improve the course for next year?

Table 1. Results of the student survey of the PHYS3006 module administered during September 2011. The results are discussed in the text.

Statement	Score
The course is effectively administered	7.70
Laboratory reports require a reasonable amount of time and effort	6.40
Laboratory reports are marked fairly	5.63
Marked laboratory reports are returned promptly	5.00
Demonstrators have a constructive attitude	7.00
The research project was very stimulating	8.00
The feedback sessions on projects are valuable	7.10
The project assisted me to improve my data analysis skills	7.60
The project improved my ability to write concisely and clearly	7.20
Mark allocation reflects the right emphasis in the course	6.30
I would recommend this module to other students	6.60
The department has a positive image amongst students	7.30

The results for a selection of the multiple response assertions are tabulated in Table 1. It is clear from these results that students attach great value to the major project. This is corroborated by the responses to the open-ended questions where the project was highlighted as the most valuable aspect of the course (18/25 students). The electronics experiments were highlighted as one of the least valuable aspects of the course by a large minority of students (10/25 students). A significant number of students mentioned that a short background course related to the electronics component would improve the impact of the electronics experiments, while others suggested that a short electronics project would improve the module. The low scores for the two items related to the fair marking and prompt return of laboratory reports (see Table 1) is of grave concern, and these were further highlighted in the responses to the open-ended questions.. A more structured method of handling report submission and marking was suggested by several students, as was the lack of comments by demonstrators on marked reports. Despite the problems with the marking and returning of set experiment reports, the set experiments were identified as a valuable aspect of the course (10/25 students).

4. Changes made to the PHYS3002 module for 2012

Two significant changes were introduced for 2012. These are an automated system for the submission and return of the reports for the set experiments, and the introduction of a small electronics project. Brief details of submission procedure are given in this section. The electronics project will be done in the second half of 2012, and will not be discussed in this paper.

4.1. Set Experiment Report Submission Procedure and Assessment

An automated web-based application was developed for the submission and return of reports, in response to the concerns raised by students in 2011 concerning the marking and returning of set experiment reports. Students are able to access the application using their favourite web browser from any location with an internet connection. They are able to upload a PDF file containing their lab report, and direct it to a particular demonstrator. Once the report is successfully uploaded the date and time of submission and the details of the student and demonstrator concerned are recorded in the database back-end to the application. The report file is stored on the web server, and an electronic copy is emailed to the demonstrator for marking. Demonstrators use Adobe Acrobat Reader to add comments to the submitted report, and save the changes to the document. The demonstrator uploads the marked report using the web application, and during this process fills in a mark schedule (including comments) for the report. The student receives both the marked lab report and a PDF version of the mark schedule, and both documents are stored on the web-server.

Table 2. Results of the student survey of the PHYS3006 module administered during May 2012. This survey follows some of the interventions introduced during 2012. The results are discussed in the text.

Statement	Score
The laboratory course is effectively administered	8.93
Set experiments are a valuable part of the course	8.39
The time and effort required to produce lab reports is reasonable	6.15
I like the submission procedure for the set experiments	9.82
The submission procedure works effectively	9.82
The electronics experiments are a valuable part of the course	6.25
The handouts for the electronics experiments are adequate	5.54
The demonstrators for the electronics course are effective	7.86
The theoretical background provided for the electronics component is adequate	4.82
The electronics component would be improved by a series of lectures	8.39
The electronics learned will be of future practical use	5.36
I would recommend this module to other students	6.43
The School of Physics has a positive image amongst students	7.32
I intend to pursue a career in experimental physics	5.18

5. Mid-year Student Assessment – May 2012

As part of the ongoing evaluation of the course a further student survey was administered following the conclusion of the first semester of the module in May 2012. The survey is designed to evaluate the changes that were introduced to the submission and return of the set experiment reports, to probe further the issues that the students appear to have with the electronics course, to probe student impressions of each of the set experiments, and to elicit student impressions of the demonstrators responsible for each experiment. The results of the survey as they relate to administration, the set experiments as a whole, the report submission procedure, and the electronics experiments are tabulated in Table 3. It is clear from the survey that the set experiments are regarded as a valuable aspect of the course, and that both the administration of the course and the submission procedure have the approval of the students. The problems raised by the student cohort of 2011 regarding electronics experiments are echoed by those of 2012, with the handouts and theoretical background once again receiving low scores. The high score obtained for the suggestion that some theoretical background be provided for the electronics experiments indicates that this should be addressed for 2013. This conclusion is supported by comments made in the open-ended questions.

Table 3. A summary of the student survey of May 2012 for each of the Set Experiments. The results are discussed in the text.

Statement	Experiment							
	1	2	3	4	5	6	7	8
Demonstrator provided sufficient information to do the experiment	7.81	8.44	9.06	8.61	8.33	7.50	8.61	6.43
Handouts adequate	6.88	7.50	7.50	7.22	5.56	6.39	7.78	6.07
Equipment adequate	4.06	6.88	9.38	6.94	8.89	8.06	8.61	5.71
Fundamental physics was learned	7.50	7.81	9.44	8.33	9.17	80.60	8.61	5.36
Demonstrator provided lab report guidance	5.94	8.13	9.06	8.06	8.89	5.28	7.22	3.93
Report marked fairly	7.50	5.50	8.75	8.21	8.75	5.31	6.88	2.50
Report returned promptly	1.50	3.93	8.75	8.57	6.88	3.06	4.17	0.00
Experiment increased interest in experimental physics	5.63	6.43	6.88	5.56	6.67	5.83	5.28	3.21

A section for each of the set experiments was included in the survey. These results are displayed in Table 3. While an appreciable number of the experiments are being demonstrated adequately with adequate equipment, there are worrying issues raised with regard to equipment, documentation and demonstrating for several experiments. These issues must be addressed for 2013. Praise and criticism for particular demonstrators in the open-ended section underline the results shown in Table 3.

6. Conclusions

A description of, and an ongoing evaluation of, the Advanced Experimental Physics and Project III (PHYS3006) module offered at WITS has been presented. It is clear that changes were, and still are, required to the module so that it offers students both a high-quality well-taught module, and an excellent impression of experimental physics. The work described is part of a re-development of the Physics Major Laboratory Curriculum at WITS.