2015

Exploring Technology Enhanced Instruction and Assessment in the Advanced Physics Laboratory

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Recommended Citation

Meade, A. (2015). *Exploring technology enhanced instruction and assessment in the advanced physics laboratory. DIT Teaching Fellowship Reports 2014-2015*

5 Exploring technology enhanced instruction and assessment in the advanced physics laboratory

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Abstract

The development of a strategic, thoughtful and reflective approach to the undertaking of experimental work is key to the development of physicists and physical scientists. This project undertook to remodel senior physics laboratories to adapt to changing skillsets required in the workplace and to instil the graduate attributes necessary for flexible employment in physics and related disciplines. The objective of this project was to foster an enquiry-based model that has been shown both to help engage the students with their subject and develop habits of experimental approach appropriate to physical scientists. The project used e-assessment methods and electronic documentation of student experimental planning, reflection and data recording, while adjusting laboratory instructions and resources. These adjustments included minimising experimental procedures such that this created a less restrictive and more free-form experimental experience, challenging the students to plan prior to experimental work and reflect afterwards. A number of evaluation techniques were used to measure the impact of these changes, including an anonymised on-line survey using the University of Colorado E-CLASS (Colorado Learning Attitudes about Science Survey for Experimental Physics) survey and peer evaluation of experimental reports. The E-CLASS survey was also taken by School of Physics staff to provide a measure of the expert view. The success of this new approach to laboratory instruction is seen in the general alignment between student views of issues of importance in experimental approach. This innovative approach to laboratory instruction will continue to be evaluated and refined for future student cohorts.

Keywords: technology, electronic instruction, physics laboratory

Introduction

> Equipped with his five senses man explores the world around him and calls the adventure Science.
>
> (Edwin Hubble, *Harper's Magazine* 1929)

Laboratory instruction and learning in the laboratory is a hugely important component of the development of professional scientists in the experimental sciences, particularly so in physics. This is often invisible outside of teaching institutes with the result that this type of instruction can be seen as unstructured and costly (Baruch 2014; Trumper 2003). Contrary to this view, students who learn to innovate and be creative within the laboratory can in the future apply these skills on a grander scale within a research environment or in the transfer of technological innovations to the market. Therefore engendering a degree of freedom to explore within the laboratory environment can be more fruitful from a learning perspective than in-class instruction alone (Baruch 2014). Where in-class instruction can actively engage students in solving conceptual problems using physical principles, in-laboratory instruction focuses on actively engaging students in solving problems of measurement or demonstration of physical effects. The learning outcomes and skills developed within each type of instruction are distinct, but of equal importance.

Laboratory instruction is often asked to reinforce the theoretical introduction of ideas that have been introduced within the lecture. Traditional laboratories typically demonstrate a well understood phenomenon or a well-defined quantity.

This can be illuminating but can also be limiting; students may not identify connections between concepts if they are not exposed to a wider view of examples from within their subject. This type of instruction can frequently be procedural, teaching students the technical aspects of performing experiments rather than the creative and inquisitive skills required for the design and refinement of experimental approaches, which is the essence of experimental physics (Zwickl, Finkelstein and Lewandowski 2013). It is the latter type of approach which is favoured within the senior laboratory as one which produces the skills of enquiry commonly viewed as being particular to a professional experimental physicist (Ibid.). In addition empowering students to be inquisitive in a logical and thorough manner allows them to explore beyond the boundaries of the experiment. This is closer to the authentic research experience of a graduate student where direction is limited and the student must strategise.

This approach to laboratory instruction can often be resource intensive, with staff to student ratios in the region of 1:10 often required (Beun 1971; Blue, Bayram and Marcum 2010; Zwickl, Finkelstein and Lewandowski 2013). It is also essential to give students adequate time for reflection coupled with appropriate intervention and feedback. Both of these requirements place stresses on the teaching resources within the laboratory. A further stress on this resource is generated by the need for oral assessment of progress within the laboratory; it is frequently difficult to ensure that timely feedback and/or appropriate oral assessment is given to the student.

Recent Developments in Senior Physical Laboratory Instruction

Although the literature is replete with examples of the implementation and effectiveness of modern approaches to in-class instruction in physics (such as active learning) (Deslauriers, Schelew and Wieman 2011; Meltzer and Thornton 2012; Freeman et al. 2014), the same cannot be said of approaches to in-laboratory instruction. However, clear direction can be taken from the in-class active learning literature on the impact of active engagement and self-direction on comprehension and retention of knowledge, together with its engendering a sense of control and responsibility in students over their own learning (Deslauriers, Schelew and Wieman 2011; Freeman et al. 2014). Various examples of modernisation of laboratory programmes focussing on specific disciplines within physics have been described, including optical spectroscopy (Blue, Bayram and Marcum 2010), laser physics (Henningsen 2011), and quantum mechanics (Galvez et al. 2005; Pearson and Jackson 2010). At the University of Colorado, Boulder, a full renewal of a senior physics laboratory programme has recently been undertaken and is described by Zwickl, Finkelstein and Lewandowski (2013). Aside from modernising the experiments themselves, this work outlines a strategy for this process:

(a) identifying a set of learning objectives is a key component of the overall process;
(b) designing and optimising the experimental apparatus such that more than one experiment can be performed and more than one learning objective achieved using any given apparatus;
(c) evaluation of learning outcomes using a combination of written and oral assessment;

Internationally there are a variety of learning goals in the senior laboratory experience, including the formation of their strategies around experimental design, the development of measurement technique, uncertainty analysis, computational modeling and inquiry oriented and research experiences. The learning objectives (LO) set out by Zwickl, Finkelstein and Lewandowski (2013) may be summarised as follows:

1 Modelling – this entails describing, or using a description of the physical system being investigated, together with modelling the measurement system being using during the investigation, and statistical analyses of data to compare with the mathematical description of the system.
2 Design – this entails designing the experimental apparatus together with appropriate trouble shooting.
3 Technical – this entails understanding the operation of test and measurement equipment, interfacing the experimental apparatus with computers and the associated data analysis software, and implementation of appropriate analytical techniques.
4 Communication – this entails producing cogent argumentation in favour of, or against, the hypothesis of the experiment on the basis of the experimental results, and communicating this through written reports and oral presentation.

Most senior laboratory programmes at university level have similar learning objectives, including those at the School of Physics in the Dublin Institute of Technology. While modernisation of equipment and design of modern experiments allowing deep enquiry into physical effects can be inspirational to students and can more readily engage them, supports must be put in place in the laboratory environment to allow students properly to achieve the learning objectives. In particular, tuition is often required to supply students with the fundamental knowledge of technical computing, interfacing and data analysis techniques as part of LO 3; a more efficient approach to this is to give students access to electronic video resources explaining the theoretical and practical aspects of these issues, with Q+A sessions given in the laboratory by a tutor (Zwickl, Finkelstein and Lewandowski 2013). LO 4 can be evaluated by oral examination of the student and evaluation of their written report, with almost immediate feedback. Difficulties arise in providing adequate feedback in a timely fashion to enable students achieve LO1 and LO2, mainly due to restrictions on teaching resources. Electronic asynchronous tutoring and peer-collaboration and tutoring may both be resources that might improve student achievement in this regard.

Methods for Evaluation and Transformation of the Senior Physical Laboratory

Experimental science in the laboratory requires that students learn a range of skills and approaches to bring experimental investigation from the research question stage through experimental design, prototyping, result acquisition, analysis and interpretation, and evaluation of outcomes. This allows each individual student to become an independent, self-reliant investigator who can then use their inspiration and actively learn by examining their own ideas and attempt various avenues of investigation. This transformation agenda is intended to give students a passion for experimental science and a confidence in their habitual approaches and strategies. Capturing the evolution of the students' thoughts and actions within a laboratory setting has traditionally relied upon the written laboratory report. With the advent of electronic recording mechanisms and the increased use of these media by the students it is possible to use other forms of reporting to analyse the students' learning.

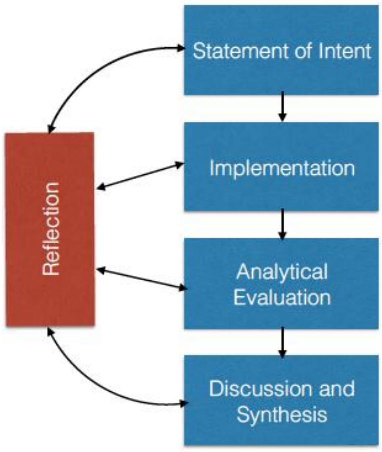

Figure 5.1: Schematic of the experimental process

The process of exploration within a given advanced physical experiment is often non-linear (see Figure 5.1). Despite the fact that there is a logical progression from one stage to the next, there tends to be a process of iteration within the experiment during which various approaches to the measurement or simulation are modified and honed to optimise the experiment. An important element of experimental laboratory instruction at the advanced level is also to provide minimal direction on the conduct of the experiment (Henningsen 2011; Masters & Grove 2010; Zwickl, Finkelstein and Lewandowski 2013). All of these approaches are designed to produce physical scientists who understand the experimental process in the round and who are prepared for work in industry and further training as professional physical scientists (Zwickl, Finkelstein and Lewandowski 2013).

As part of the transformation of the senior physical laboratory at DIT the following series of measures have been implemented in the 2014-2015 laboratory session:

1. Students are required to produce a short 'Statement of Intent' (SoI) prior to beginning the experimental part of their laboratory. This statement comprises the students' vision, experimental strategy and planning around the conduct of the experiment before beginning, together with notes on expected results and contingencies where applicable. This is a key component of research planning that all professional scientists undertake at the experimental planning stage and is viewed as being a very important component of a student's understanding of the conduct of experiments. The students are required to supply this component of their work electronically in the form of a wiki, which is accessible to the instructor only, and through which the instructor can give feedback asynchronously and advise on modifications to the experimental approach or strategy; overall this facilitates the instructor giving feedback to students within large groups that are not seen face-to-face during the laboratory period.
2. The students are supplied with laboratory instructions that are optimised and minimized for each experiment. This allows the experimental approach and outcomes for each experiment and each student to be somewhat elastic and thus the outcomes of the experiment more accurately reflect the abilities of the students.
3. During the conduct of the laboratory, and in particular at the end of the allotted period for the experiment, the students are asked to reflect upon the outcomes of their experimental approach vis à vis the suitability of their initial strategy for satisfying the experimental objectives. They are required to record any changes they have implemented in light of this reflection and highlight whether these changes have had any effect. This reflection on the part of the student is intended to both inform them for their future conduct of the experiment and inform the instructor on their perceptions of the conduct of the experiment for both marking and feedback purposes. A component of the laboratory marks was awarded for the completion of the electronic records for each of their experiments.
4. As a means of informing the students regarding the quality of laboratory reports achieving the maximum marks the students were also supplied with redacted reports from their peers and asked to mark these reports. Again a component of the laboratory marks were awarded to each student for engaging with this activity.
5. Finally the students were asked to complete the E-CLASS survey questionnaire as a means of evaluating the effectiveness of the complete laboratory programme in terms of its impact on changing the students' approaches to the conduct of their experiments and their perceptions regarding the importance of the components of the classical experiment approach.

The E-CLASS Survey (Colorado Learning Attitudes about Science Survey for Experimental Physics) has been developed by the University of Colorado at Boulder and has to date been altered through several iterations to improve its effectiveness in terms of analysing students' perceptions and approaches to experimental physics (Adams et al. 2006; Gray et al. 2008; Adams and Wieman 2011; Zwickl, Finkelstein and Lewandowski 2013; Zwickl et al. 2014). It is an epistemology and expectations survey which analyses the students' beliefs regarding the conduct of experiments in physics and their theories on knowledge and learning.

The students are given a series of approximately 30 statements and asked to rate their agreement with each of the statements on a Likert scale. They are asked to provide ratings in terms of their own view and their perception of what the view would be of a qualified professional experimental physicist in research or industry. In addition faculty at the School of Physics in DIT were asked for their responses to the survey to provide a rating of expert-like responses.

The survey responses are evaluated both in terms of the distribution of responses and the adjustment in the distribution of responses pre and post the laboratory programme. This latter approach was not implemented in the

2014-2015 laboratory programme as the survey was given to the students after the laboratory programme. In addition the surveys are evaluated in terms of the fraction of students with expert-like responses to each question.

The statements are intended to evaluate the students achievement and acceptance of widely accepted laboratory learning goals and are therefore intended to be applicable to any laboratory programme regardless of the particular nature of its focus. Typical issues the survey addresses are (Zwickl et al. 2014);

(a) the time consuming nature of laboratories and their impact on student enthusiasm;
(b) the fact that students replicate experiments with known results and the impact of this on their experimental design and reflection;
(c) the fact that senior laboratories typically use advanced apparatus which students may treat as black boxes which they do not understand or investigate;
(d) the fact that uncertainty analysis is typically seen as a procedural algorithmic activity by the students rather than a means to understand the significance of the results;
(e) the fact that students often approach experiments as a means of aligning with the expectations of the instructor for grading purposes rather than a means of development of personal understanding, insights and the development of their communication.

The statements themselves (Appendix 5.1) may be grouped into eight categories relative to their addressing of the following issues:

- Personal interest;
- Real world connections;
- Conceptual connections;
- Sense making/efforts;
- Problem solving sophistication;
- Problem solving confidence;
- Problem solving general;
- Applied conceptual understanding.

These categories were not incorporated in the current work but can aid in understanding of the student responses in future analyses.

Results

E-CLASS survey

Institutional ethical approval was obtained for the conduct of the surveys detailed in this report. The E-CLASS survey was administered to the students and faculty as a Google form with responses anonymised. Student responses were collected for the senior lab cycle (N=37) which included third year students (N=27) and fourth year students (N=10). The expert opinions were recorded from the lecturing staff (N=6). In total 30 statements were presented to the students and staff. A full list of statements can be found in the appendix. All responses were recorded on a Likert scale. In this analysis the scale is considered as an interval scale and mean and standard error was calculated.

The most obvious result amongst the responses is that there is no significant difference between the expert's opinion and the students' perception of an expert's opinion in any of the statements presented. For further analysis the statements are sub-divided into two categories, responses to statements in which the average students and expert's opinion differ significantly and statements in which they do not. Diagrams showing the full results for the two categories are shown in the appendix, Figures 5.A1 and 5.A2. To illustrate the differences two such results are plotted in Figure 5.2.

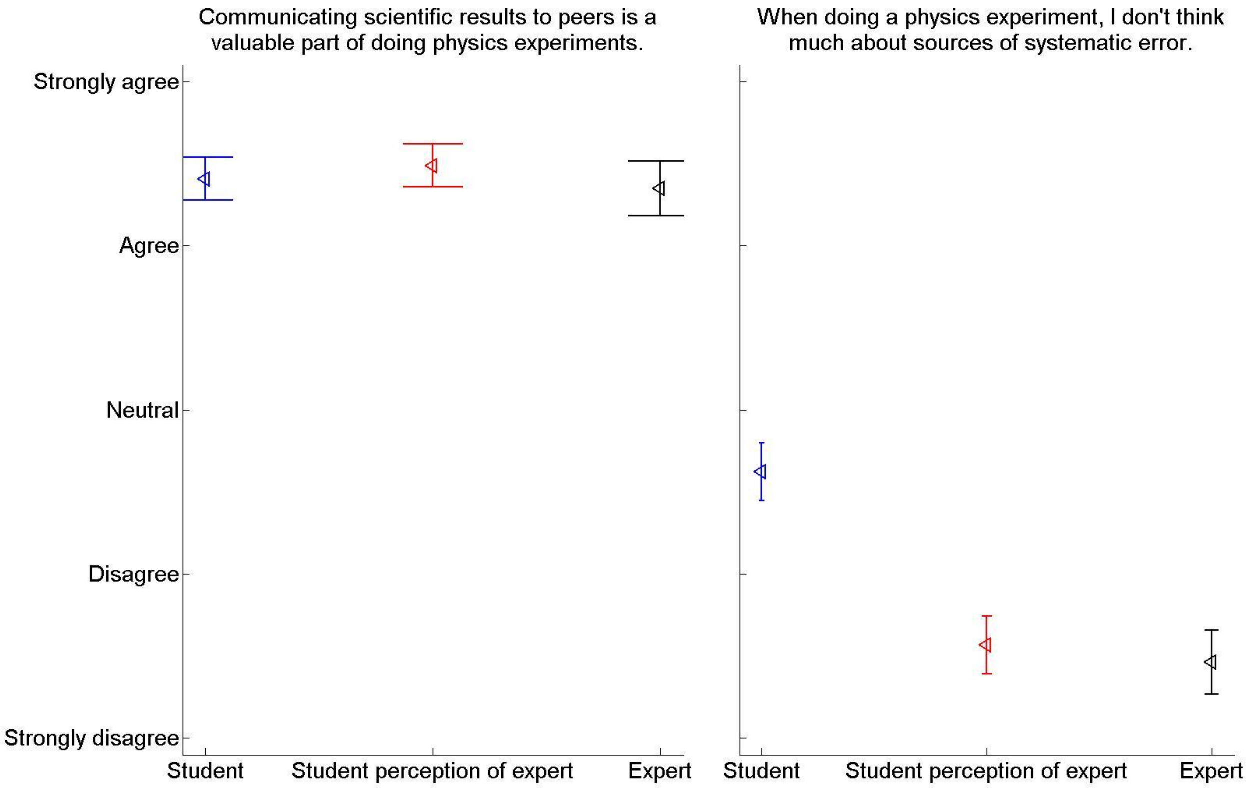

Figure 5.2: Average responses to two statements on the ECLASS survey. Error bars represent the standard error and it can be seen that the student and expert opinion differ significantly in the responses to one of the statements.

As we can see in Figure 5.2 the students and staff agree that communication is a valuable part of doing physics. In total the results indicate many aspects of experimental physics in which the students' and the staff (experts) agree. These can be considered areas of strength in which the students consider themselves as working to an expert level. Full results are shown in the appendix in Figure 5.A1 which clearly illustrates the many strengths of the DIT laboratory programme.

In addition, in Figure 5.2 we can see that the students believe that they should, but do not, consider systematic errors. This result is a clear indication that systematic errors must be stressed more in the development of the laboratory. In total many areas for development are indicated by the results of the survey. Full results for these areas can be seen in the appendix in Figure 5.A2. To probe whether these issues arise predominantly in the Year 3 as opposed to the Year 4 cohort, survey responses are separated by year. No statistically significant improvement is shown in the responses given by the fourth years although a higher proportion of expert-like responses to the survey questions was obtained from the fourth year cohort as compared to the third cohort, reflecting an evolution in understanding between the last two stages of the programmes.

This project has as one of its aims to develop a more student-led inquiry-based laboratory experience and to move away from the 'cook-book' style experimental instructions. As is detailed earlier the students were supplied with laboratory instructions that are optimised and minimised for each experiment. In addition students were encouraged to make predictions and to run small datasets and check their proposed methods and results were reasonable. It is clear, however, from the responses to two survey questions shown in Figure 5.3 that more work is necessary in this area; some students feel that they can 'follow instructions without thinking about their purpose', others do not feel that they should 'make predictions to see if my results are reasonable'.

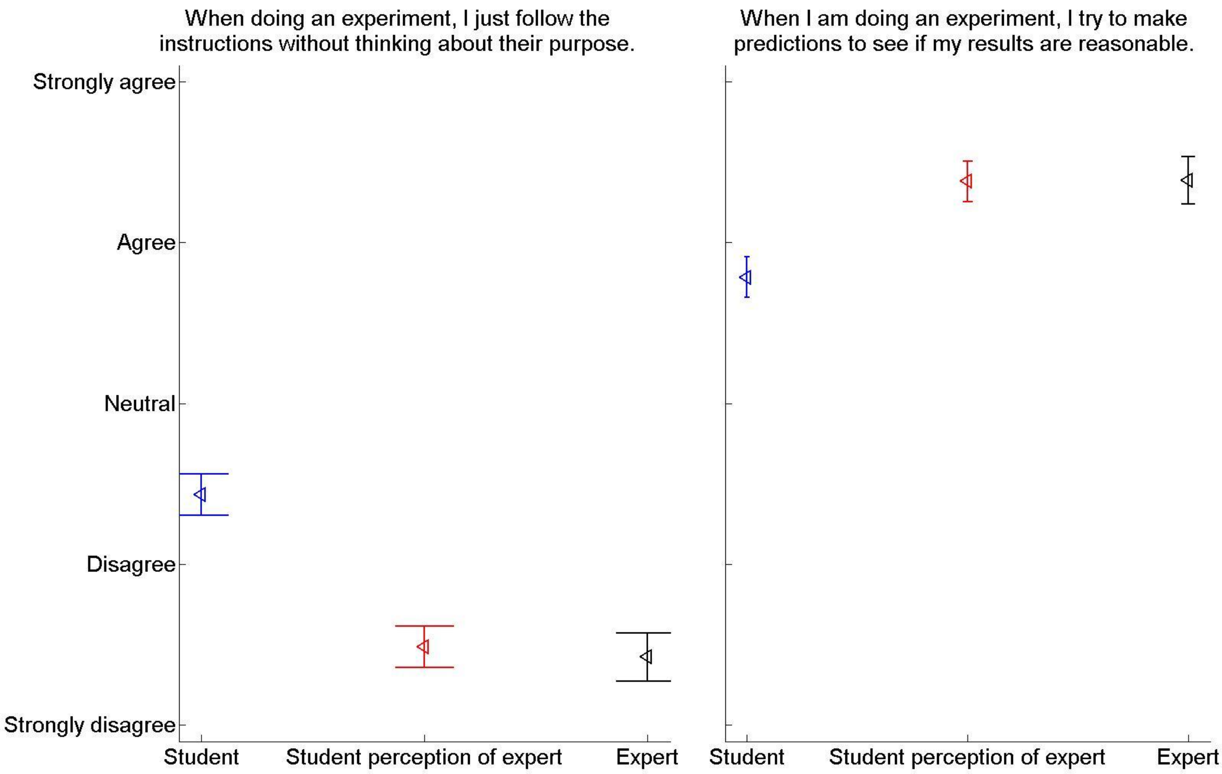

Figure 5.3: Average responses to two statements on the E-CLASS survey. Error bars represent the standard error.

The E-CLASS survey is designed as a pre- and post-instruction survey to examine the effect of lab instruction on the students. Due to time constraints the survey was presented to the students post-instruction. However, the study remains on-going and the third year students' post-test will become the fourth year students' pre-test in the coming academic year. This report is to become the beginning point for more detailed analysis of the collected data from this ECLASS survey including the organisation of statements by categories.

Student and Staff Feedback

Feedback was collected from students in the form of short interviews with a number of students. Students were selected for interview to represents different types of students ranging from weak to strong academically and highly to weakly motivated. Third year students were interviewed by a member of staff involved in the project and the supervision of the lab and therefore bias may have influenced student responses.

Questions probed the new structure asking questions on the major changes, i.e. the pre-laboratory SoI, the less descriptive manuals and the requested reflections by the students. Many positive aspects were reported on by the students. For instance, the majority of students claimed to be more prepared coming into the due to the SoI: '*you know exactly what you are doing coming in, great advantage'*.

It was noted by staff that the SoIs gave an important chance to catch students' misconceptions before the lab class began. The SoI also gave a good starting point for discussion with the students about the experiment and it became very easy to see how much work the students had done before coming to class.

When discussing the reflection students reported that the exercise made them think about different aspects of the lab: '*Good idea, makes you think, easier to do if there were problems (sic with experiment)'.* It appeared that the students felt the major difference between the reflections and writing a conclusion or abstract was that they could discuss what went wrong in the reflection or as one student put it: '*great for complaining'.*

It was felt by the staff that the less descriptive manuals worked well. One student gave remarkable feedback: '*If you ask me something I can tell you, not just recite something, I felt if you asked me in six months I'd still remember'.* It is hoped that the student was not telling the instructor what they wanted to hear.

Not reported on by students but mentioned by staff was that the students seemed more engaged with the process, eager to see if their proposed experimental plan in their SoI was correct. Throughout the year it was found that students completed experiments using methods different to those removed from the manuals. Often it was difficult to get students to do short data runs to test their experimental set-up and reflect on the method they have chosen. This is noted also by the students in their responses to the E-CLASS survey.

Most of the negative feedback related to what we have named here 'teething issues'. The most frequently mentioned were issues relating to wifi coverage in the lab and the wiki system chosen as the platform for the students' online electronic journals. If the internet connection was dropped all unsaved work would be lost, which was understandably frustrating to students. To address this in the coming academic year the system is to be changed from using the wikis tool to using the Google applications, Sheets and Docs. These provide the same advantages of online reporting but are more user friendly with increased functionality for data analysis and presenting of results. They also allow the user to work without an internet connection and save automatically when the connection is resumed.

The other main issue was the perceived increase in workload by the students. The students felt that the electronic reporting took much longer than the traditional reporting. Many efforts were made by the staff prior to the implementation of this method to balance the workload and the number of requested formal reports for assessment was dramatically reduced. However, many of the students still felt that it was very time consuming. [It is] '*like writing a full report, takes forever', [it is] 'More time consuming than lab book'.*

The reduction in the number of assessed formal reports did not seem to have a negative effect on the quality of submissions. A perceived higher quality of submitted formal reports was reported by one of the authors.

It was noted by staff that some highly-motivated students created electronic submissions which resembled more a formal report than an electronic replacement for the traditional log-book. It was confirmed in feedback to these students what was required for the electronic submissions. Unusually the students did not note the increased effort and time it took in the lab to complete experiments with the reduced instructions. Without step-by-step instructions the time it took students to complete experiments increased substantially. In some cases if students used an incorrect method and did not use a small data run to test their proposed method they did not have sufficient time to finish the experiment. However, it was felt that valuable lessons were learnt in the process.

Recommendations to DIT

The feedback from staff and students are that the changes made have had a positive effect on the senior laboratories. Feedback from students is very positive with students reporting on the advantages of the developments to increase their learning potential in the laboratory. The students feel that the pre-laboratory statements of intent have better prepared them for the laboratory. The online submission of the pre-laboratory work has also provided instructors with opportunities to provide feedback to students before they enter the laboratory and also equip them with opportunities for quality targeted discussion with students in the laboratory. It was reported by staff and student feedback that the less descriptive manuals create deeper learning experiences with students designing their own experimental setups. Electronic log books have also increased the opportunities for timely feedback to the students who receive the feedback as soon as the lectures have submitted, rather than this occurring within the timetabled laboratory time.

E-CLASS survey, although only used as a post-test survey in this report provided many areas of strengths and development in the senior laboratory. Areas of strength are considered to be areas in which the students and the expert opinions were not significantly different. Conversely, areas for development highlighted here would be the students' consciousness of areas in which their opinion differed significantly from that of an expert, and to instill this consciousness progressively over the course of the senior laboratory programme.

Proposed Future Work

The developments in the lab will continue with the only major change being the change in the platform used for electronic reporting. The system is changed from wiki reporting to reporting using Google applications, Sheets and Docs.

References

Adams, W. K. et al. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey. *Physical Review Special Topics – Physics Education Research* 2, 010101.

Adams, W. K. & Wieman, C. E. (2011). Development and Validation of Instruments to Measure Learning of Expert-Like Thinking. *International Journal of Science Education.* 33: 1289–1312.

Baruch, J. (2014) Practical science has a global reach and appeal. *Nature* 507, 141.

Beun, J. A. (1971) Experiences with a Free Undergraduate Laboratory. *American Journal of Physics.* 39: 1353.

Blue, J., Bayram, S. B. & Marcum, S. D. (2010) Creating, implementing, and sustaining an advanced optical spectroscopy laboratory course. *American Journal of Physics.* 78: 503.

Deslauriers, L., Schelew, E. & Wieman, C. (2011). Improved learning in a large-enrolment physics class. *Science* 332: 862–4.

Freeman, S., Eddy, S.L., McDonough, M., Smith, M.K., Okoroafor, H.J. and Wenderoth, M.P. (2014) Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, USA* 111: 8410–5.

Galvez, E. J. et al. (2005). Interference with correlated photons: Five quantum mechanics experiments for undergraduates. *American Journal of Physics* 73: 127.

Gray, K. E., Adams, W. K., Wieman, C. E. and Perkins, K. K. (2008). Students know what physicists believe, but they don't agree: A study using the CLASS survey. *Physical Review Special Topics – Physics Education Research* 4, 020106.

Henningsen, J. (2011) Teaching laser physics by experiments. *American Journal of Physics* 79: 85.

Masters, M. F. and Grove, T. T. (2010) Active learning in intermediate optics through concept building laboratories. *American Journal of Physics* 78: 485.

Meltzer, D. E. and Thornton, R. K. (2012) Resource Letter ALIP–1: Active-Learning Instruction in Physics. *American Journal of Physics* 80: 478.

Pearson, B. J. and Jackson, D. P. (2010) A hands-on introduction to single photons and quantum mechanics for undergraduates. *American Journal of Physics* 78: 471.

Trumper, R. (2003) The Physics Laboratory – A Historical Overview and Future Perspectives. *Science Education* 12: 645–670

Zwickl, B. M., Finkelstein, N. and Lewandowski, H. J. (2013) The process of transforming an advanced lab course: Goals, curriculum, and assessments. *American Journal of Physics* 81: 63.

Zwickl, B. M., Hirokawa, T., Finkelstein, N. and Lewandowski, H. J. (2014) Epistemology and expectations survey about experimental physics: Development and initial results. *Physical Review Special Topics – Physics Education Research* 10, 010120.

Appendix 5.1

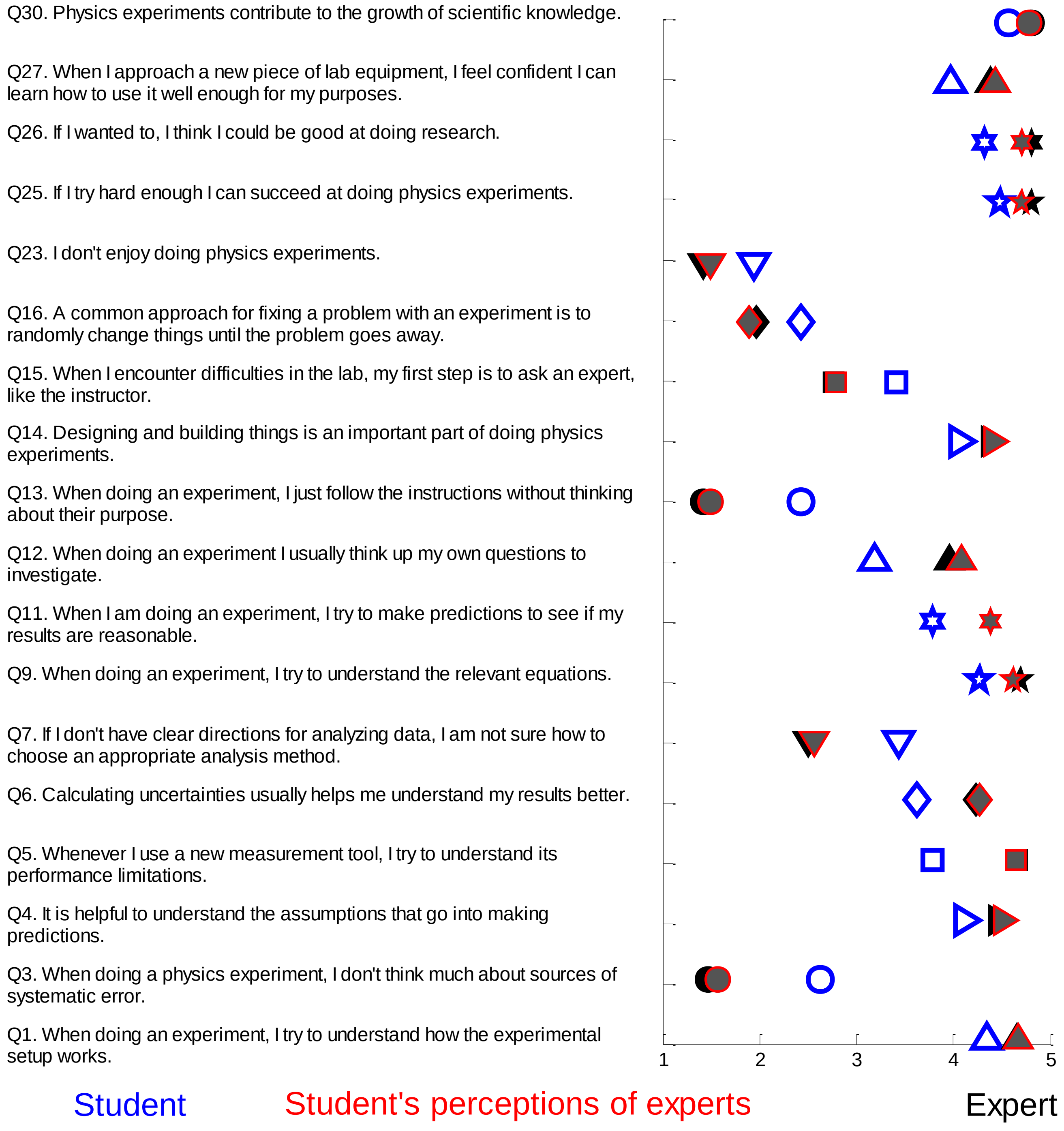

Figure 5A1: Statements in which there is no significant difference between students' opinion and that of the experts as measured by the average response and the standard error.

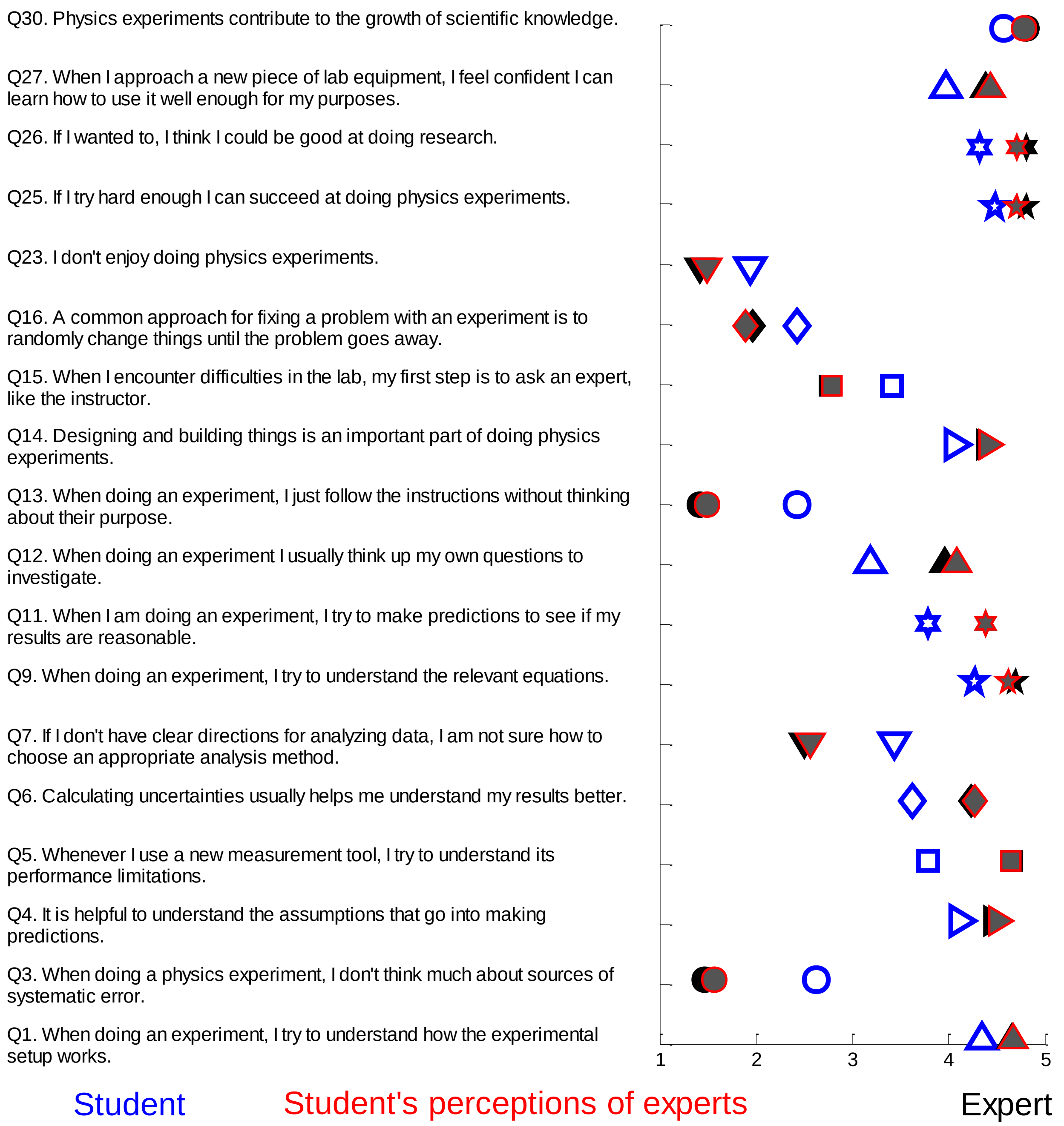

Figure 5A2: Statements in which there is a significant difference between students' opinion and that of the experts as measured by the average response and the standard error.