A disconnect between staff and student Perceptions of learning: An Educational analysis of the First Year undergraduate chemistry experiment 'Investigating Sugar using a Home Made Polarimeter'

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Supplementary Material

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I. Scientific and Educational Objectives of the Experiment

(A) Scientific Objectives

The experiment serves to promote student development at both the practical and intellectual levels. Prosaically, students use analytical balances and volumetric flasks to prepare standard solutions. Six such solutions are prepared, allowing students to work in pairs (if desired) and still have each student experience and practice weighing by difference, quantitative transfer, and the use of a volumetric flask. More importantly, students learn about the critical components of a polarimeter as they assemble the instrument themselves (see Figure 1). They experiment with rotating just the top-most polarising filter to see their effect on the intensity of transmitted light, and learn how to use the extinction point to zero the instrument. Then, the instrument is used to examine the effect on the transmitted light of different sucrose concentrations and of different path lengths at constant concentration. These results are used to prepare a simple report following a provided proforma.

At one level, the objective is to recognise that sucrose is optically active by building the polarimeter and to use it to measure that activity. At a deeper level, the experiment aims to illustrate that scientific instruments are not mysterious black boxes from which data somehow emerge, but rather that they function on scientific principles that can be readily understood. By verifying that the relationships between measured rotation, concentration, and path length are consistent with the theory presented in lectures, students see for themselves how such relationships are originally derived. Finally, by considering the accuracy of their measurement (relative to the literature value for the optical rotation of sucrose) and whether their lines of best fit extrapolate through the origin, students have the opportunity to consider the errors implicit in their results. Plots of measured rotation against concentration and path length should both extrapolate through the origin within error, but the calculated specific rotation will not match the literature value if the sucrose is contaminated with other chiral materials like glucose or fructose.

Depending on the backgrounds and experiences of students and the time available, there are numerous extension activities that can be added to the experiment. For example, students could be asked to design and carry out an experiment to investigate the dependence of optical rotation on some other variable – such as wavelength of light or temperature. Similarly, students could be asked to predict what would happen if distilled water was added to the

polarimeter, and then to test their prediction. Samples of two enantiomers could be investigated, and the resulting solutions combined to form a racemic mixture. The concentration of an unknown solution could be determined using the calibrated polarimeter. Results could even be compared to those obtained from a standard laboratory polarimeter. For more advanced students, the experiment could be paired with one involving the resolution of a pair of optical isomers as a test of purity, or a reaction involving a change of optical rotation (such as the acid-catalysed inversion of sucrose) could be investigated. The point is that the experiment is extremely flexible, and can be tailored to serve a variety of ends. It illustrates that relatively simple equipment can quantitatively allow investigations of chemical phenomena.

(B) Educational Objectives

The educational analysis of this experiment was carried out using the Advancing Chemistry by Enhancing Learning in the Laboratory (ACELL) protocols. Details of the ACELL formalism and its achievements have previously been published (Read, 2006; Buntine *et al.*, 2007; Jamie *et al.*, 2007), as has the analysis of another experiment (Read and Kable, 2007). Our analysis utilised the ACELL Educational Template (http://www.asell.org). Support materials such as student, demonstrator, and technical notes are also freely available from the website, although some materials are restricted to those who hold verifiable academic (or equivalent) status in order to control access to 'answers'.

The educational objectives of the experiment, as it operates at Flinders University, are are divided into three categories – theoretical and conceptual knowledge, scientific and practical skills, and thinking skills and generic attributes. Within each category, responses to the question 'What will the student learn?' are used to identify several learning outcomes. Those outcomes marked with an asterisk are considered to be the most important in the present formulation of the experiment, but other outcomes, including the unmarked ones, could be accentuated in other contexts. For each learning outcome, the specific processes and activities which are expected to promote student learning are described, along with the indicators that will allow both students and their instructors to determine the extent to which each outcome has been met.

Theoretical and Conceptual Knowledge

Students learn that light can be plane polarised using simple polarising filters, similar to the filters they may encounter in polarised sunglasses. The extent to which a second polarising

filter will allow transmission of the plane-polarised light then depends on the relative orientation of the two filters. In constructing a simple polarimeter, students learn about the necessary components and gain a greater understanding of their individual functions and the internal workings of a scientific instrument. As students recognise the need to zero their polarimeter, they learn about the need for a reference point in measuring relative change and experiment with a blank solution – such techniques are commonly used in other spectroscopic experiments. Student results demonstrate that the extent of rotation of the plane of polarisation is directly proportional to the concentration and the path length through the solution of the optically active substance, verifying experimentally the theory they have encountered in lectures.

Scientific and Practical Skills

The ability to accurately prepare solutions of known concentration is important for many quantitative chemical investigations, and requires techniques like weighting by difference and quantitative transfer. Using and handling volumetric flasks and analytical balances may still feel awkward to students. This experiment provides them with the opportunity to practice each of these skills. Further, whilst the individual concentrations are not checked, poor solution preparation will introduce errors into the final data that should be readily apparent. In analysing their data, students must plot and present appropriate graphical representations, highlighting key results. If the experiment is conducted properly and analysed correctly, all data sets should be modelled well by a straight line that extrapolates through the origin.

An important scientific skill exercised in this experiment involves the consideration and treatment of error. In addition to the usual measurement uncertainties, there are numerous potential sources of human error associated with the preparations of the solutions and reading of the protractor. Cumulatively, these errors should only result in a small uncertainty associated with each data point, and the intercept should be the origin within experimental error. If it is not, demonstrators should assist students in identifying significant problems that arose, and students are encouraged to account for this discrepancy in their report. The data collected are also used to estimate the specific rotation of sucrose, which is then compared to a provided literature value. In our experience, students' results are often inconsistent with the literature value, an inconsistency which could be due to measurements under non-standard conditions, but which we believe primarily result from the presence of optically active impurities in the commercial sugar – most likely glucose and fructose from

the slow hydrolysis of sucrose that occurs as moisture is absorbed. It is desirable for students to recognise the difference between a properly measured but aberrant result which conveys useful information – in this case, that the sugar is not pure sucrose – and unexpected results that arise due to controllable or inherent experimental errors**.**

Thinking Skills and Generic Attributes:

The consideration of errors described above requires that students reflect on both their results and the procedures used to obtain them. Such reflection is an application of a metacognitive control process (Byers, 2002), and one that many students have difficulty in developing (Pass and van Merrienboer, 1994; Sweller, 1994). Discrepancies in experimental work are usually taken as an indication of a poorly conducted experiment, and students are often reluctant to interpret a result as indicating a problem with the sample provided or as resulting from the breakdown of the assumptions supporting the underlying theory; instead, there is a tendency to attribute a perceived aberrant result to their own mistakes, even when no mistake can be identified and others are obtaining similar results. This activity offers the opportunity to encourage students to consider all the alternatives in interpretation of unexpected data. For example, by collecting on a whiteboard the results of each individual student or pair, the Demonstrator can discuss whether the complete data set from the class is consistent with intercepts at the origin or with the literature value for specific rotation. Interactive discussion then affords the opportunity to reach a consensus explanation in which students feel some ownership – the explanation arises from their own data and guided discussions, rather than having been mandated by an authority figure.

This experiment is designed with the intention of assisting students to recognise that instrumentation need not be mysterious in either construction or operation.

II. ACELL Workshop Survey Instrument

ASELL Project – Workshop Evaluation of an Experiment

Name of Experiment…… Date……

This experiment has been submitted to ACELL for evaluation. An important part of this evaluation process involves collecting feedback on students' experience of the exercise, which is the purpose of this survey. Your responses are anonymous, and participation is voluntary. Put your responses under ANSWERS on the right hand side of this form. If you feel you cannot answer a particular question, just leave it and go onto the next question. Erase errors thoroughly. Please note that the scale below should be used for ***only*** questions 1 to 12, as 13 and 14 have separate scales. Also, the survey is double-sided.

	A	**B**	**C**	**D**	**E**
SCALE:	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

1. The experiment works.
2. I expect that completing the experiment will effectively help students to develop their theoretical and conceptual knowledge.
3. I expect that completing the experiment will effectively help students to develop their scientific and practical skills.
4. I expect that completing the experiment will effectively help students to develop their thinking skills.
5. I expect that completing the experiment will effectively help students to develop their generic skills.
6. I expect that students will find this experiment interesting.
7. I believe that the laboratory notes, when supported with guidance from demonstrators and other resources, will provide sufficient support for students as they learn.
8. Useful assessment criteria are clearly stated.
9. The experiment requires students to participate as active learners.
10. The statement of 'required prior knowledge and skills' (template section 1.7) is accurate.
11. Sufficient background information, of an appropriate standard, is provided in the introduction.
12. The experiment provides students with opportunities to take responsibility for their own learning.

FOR EACH OF THE NEXT TWO QUESTIONS, USE THE SEPARATE SCALES INDICATED

13. The amount of time available for students to complete this experiment is:
A = 'way too much' **B** = 'too much' **C** = 'about right' **D** = 'not enough' **E** = 'nowhere near enough'
14. Overall, as a learning experience, I would rate this experiment as:
A = 'outstanding' **B** = 'very valuable' **C** = 'worthwhile' **D** = 'of little value' **E** = 'worthless'

Please turn over and complete the additional questions on the back of this form.

15. What are the strengths of the experiment?

16. What are the weaknesses of the experiment?

17. What is/are the main lesson(s) to be learnt from the experiment?

18. What improvements can you suggest for the experiment?

19. Please provide any additional comments on this experiment here.

Please place this survey in the box at the front of the laboratory.

III. ACELL Student Learning Experience (ASLE) Instrument

ASELL Student Laboratory Evaluation

The experiment you have just completed is being evaluated by a process called ASELL. An important part of this evaluation process involves collecting feedback on students' experience of the exercises, which is the purpose of this survey. Your responses are anonymous, and participation is voluntary. Put your answers by completely filling in the circle corresponding to your response to each of the fourteen statements below. If you feel you cannot answer a particular question, just leave it and go on to the next question. Erase errors thoroughly. Please ensure you also complete the additional questions on the reverse of this sheet.

Experiment title:

Instructions:
Please fill in one box only for the following 14 statements corresponding to the scale indicated by completely filling the circle ● with a **blue** or **black** ballpoint pen.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. This experiment helped me to develop my data interpretation skills	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
2. This experiment helped me to develop my laboratory skills.....	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
3. I found this to be an interesting experiment	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
4. It was clear to me how this laboratory exercise would be assessed.....	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
5. It was clear to me what I was expected to learn from completing this experiment	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
6. Completing this experiment has increased my understanding of chemistry.....	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
7. Sufficient background information, of an appropriate standard, is provided in the introduction.....	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
8. The demonstrators offered effective supervision and guidance.....	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
9. This experimental procedure was clearly explained in the lab manual or notes	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
10. I can see the relevance of this experiment to my chemistry studies.....	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
11. Working in a team to complete this experiment was beneficial	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
12. The experiment provided me with the opportunity to take responsibility for my own learning.....	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
For each of the next two questions use the separate scales indicated					
13. I found that the time available to complete this experiment was ..... **A** = 'way too much' **B** = 'too much' **C** = 'about right' **D** = 'not enough' **E** = 'nowhere near enough'	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
14. Overall, as a learning experience, I would rate this experiment as..... **A** = 'outstanding' **B** = 'very valuable' **C** = 'worthwhile' **D** = 'of little value' **E** = 'worthless'	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ

Please turn over and complete the additional questions on the back of this form

15. Did you enjoy the experiment? Why or why not?

16. What did you think was the main lesson to be learnt from this experiment?

17. What aspects of the experiment did you find most enjoyable and interesting?

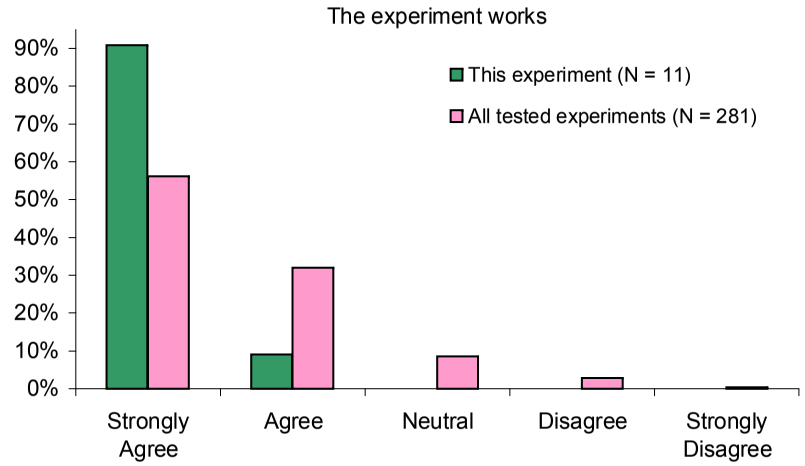
18. What aspects of the experiment need improvement and what changes would you suggest?

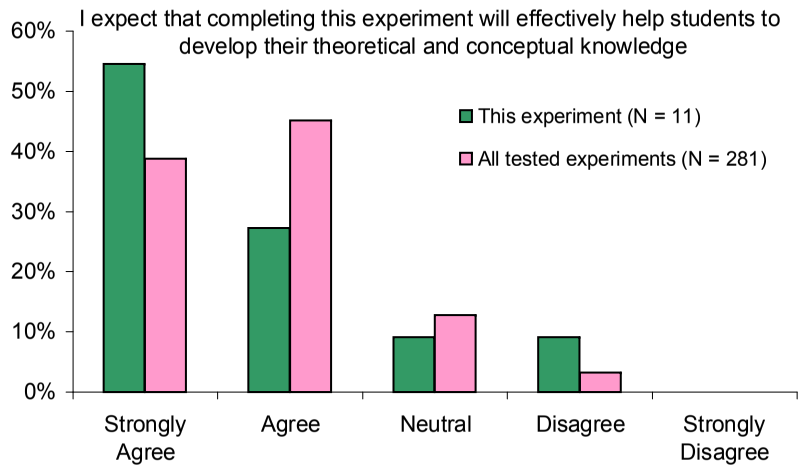
19. Please provide any additional comments on this experiment here

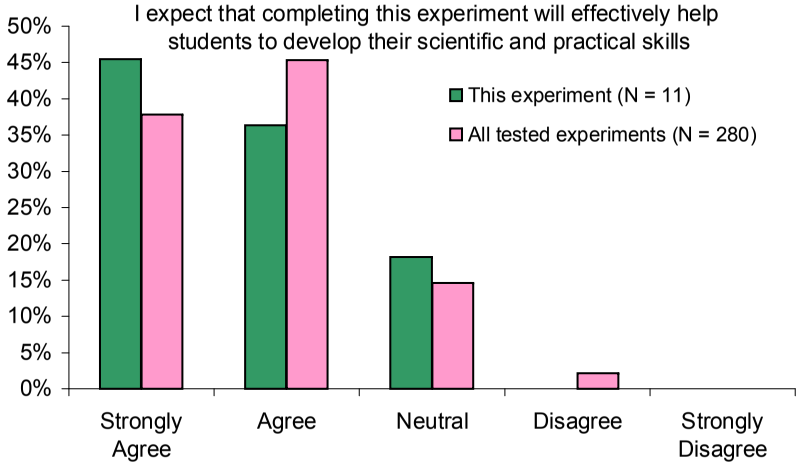
Please return this survey to your demonstrator.
Thank you for your participation.

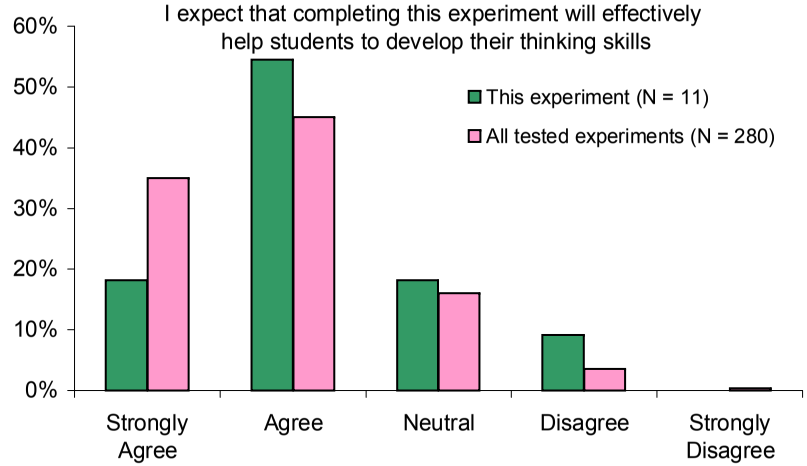
IV. ACELL Experiential Workshop Data

ACELL Workshop – Feedback from Survey A



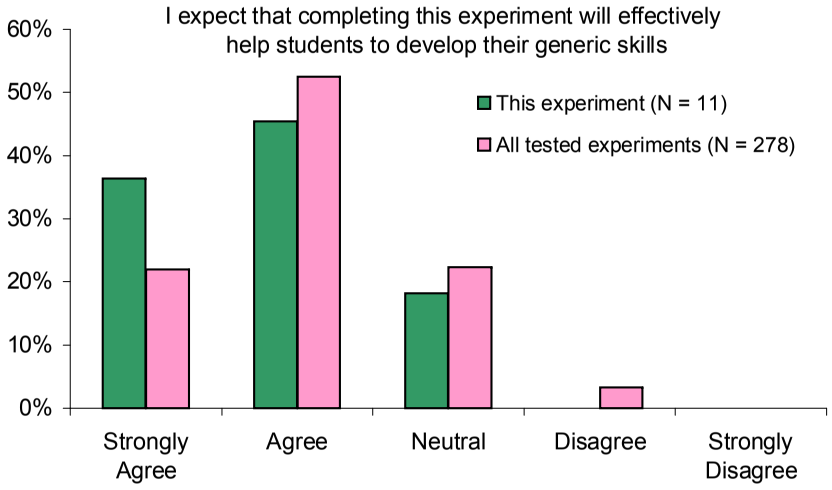


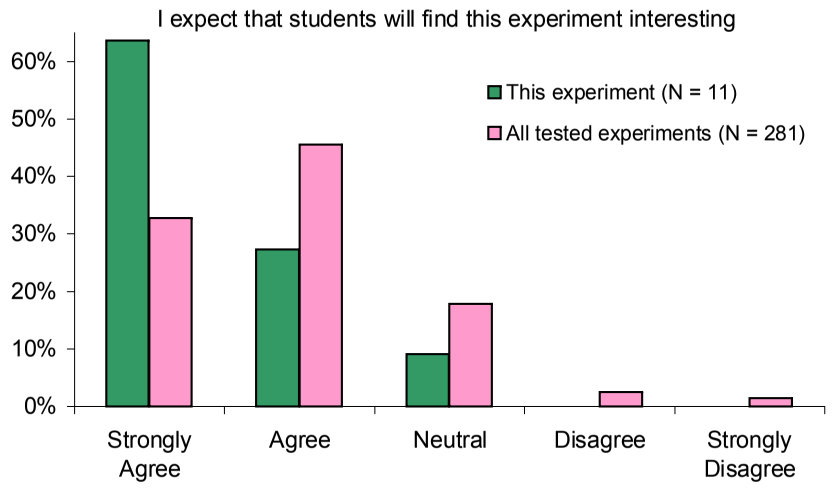


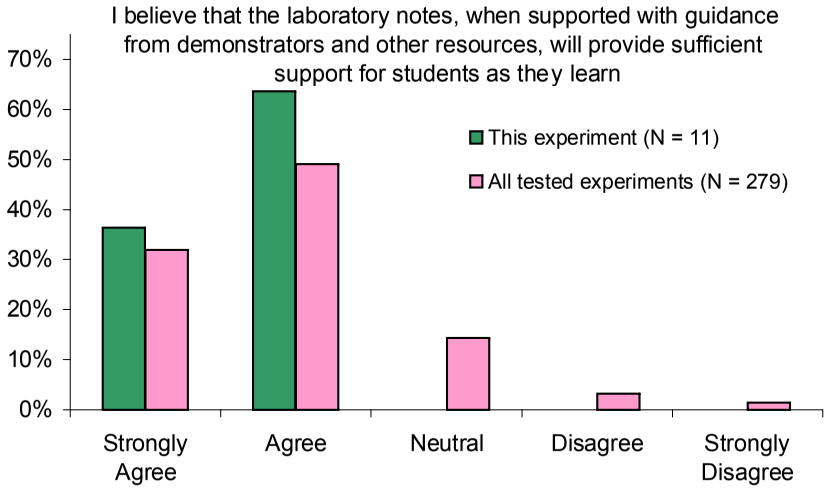


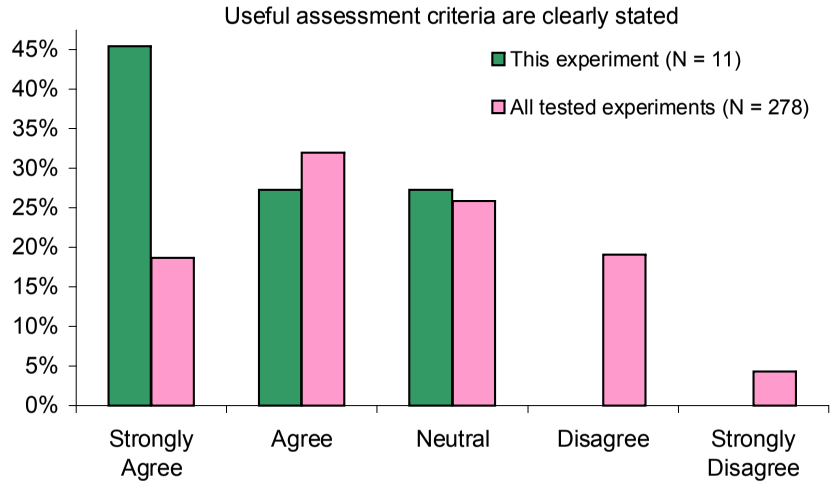
Experiment T-L3-2: Investigation of Rotation of Plane Polarised Light using a Home Made Polarimeter

ACELL Workshop – Feedback from Survey A









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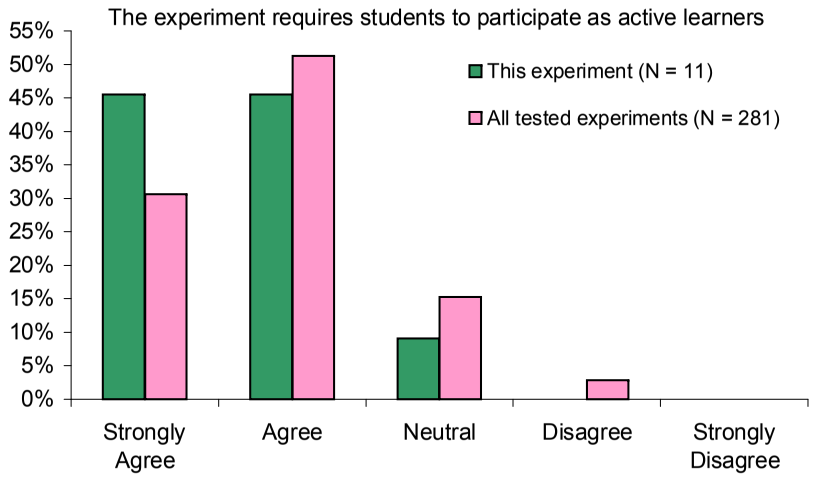
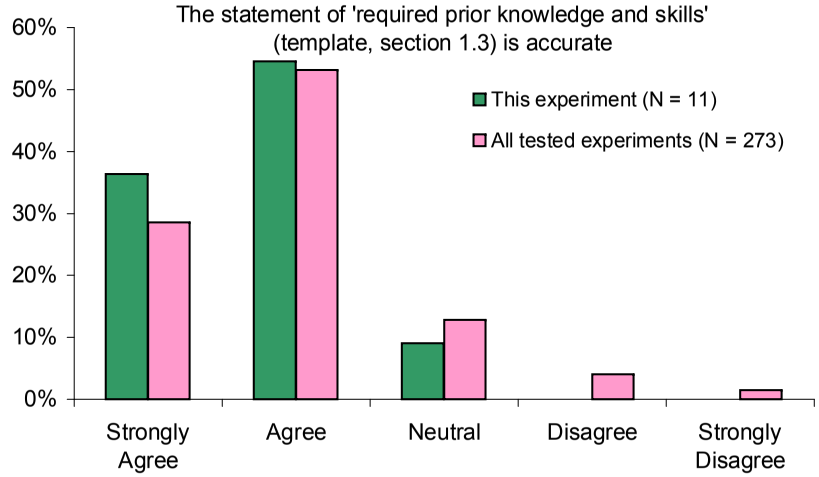
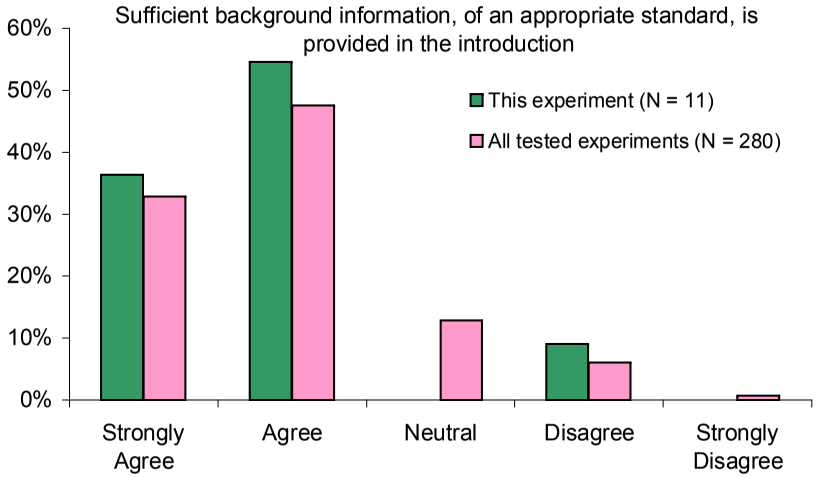
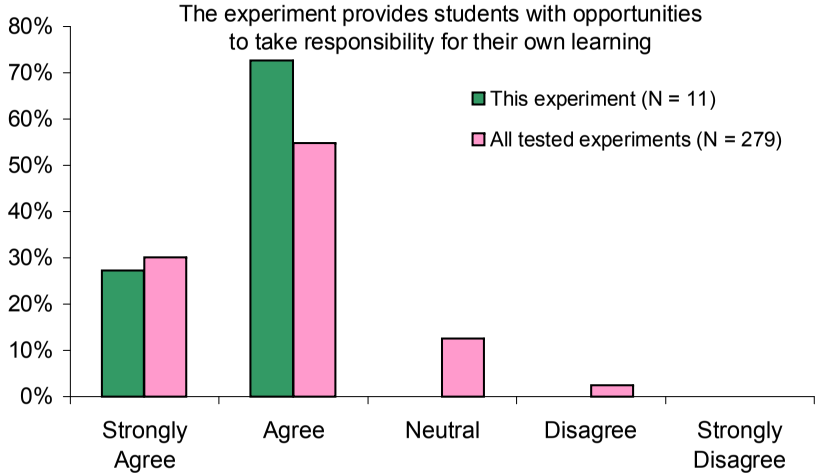
ACELL Workshop – Feedback from Survey A









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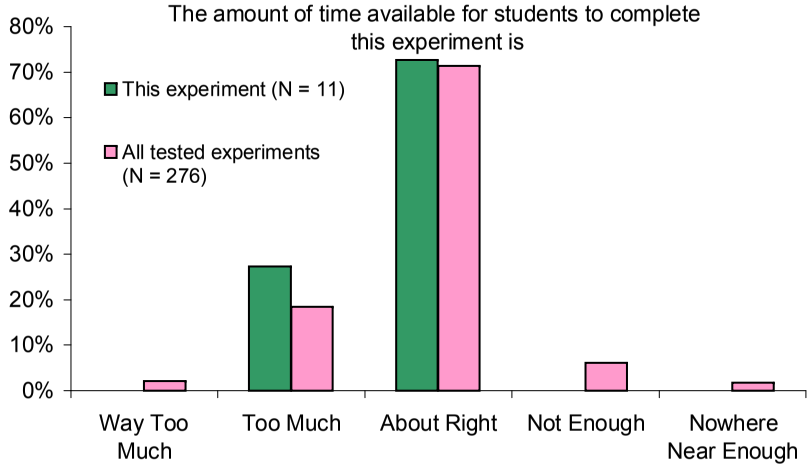
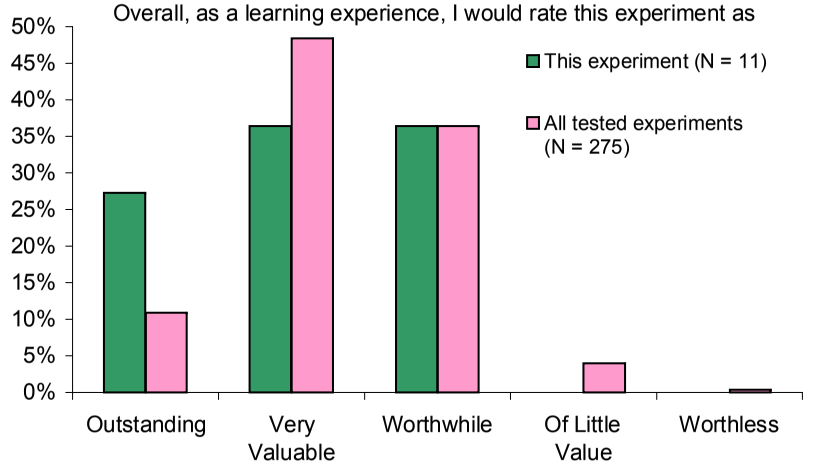




What, if any, are the notable strengths of this experiment?	
Hands on, with good team work	Relates theory of polarimetry to practice
The expeiment provided students with the opportunity to practise volumetric techniques to create solutions of known concentrations as specified	For an introduction to first year prac, the solute / solvent is safe to handle and easy to dispose of
Easy experiment to illustrate optical totation of chiral molecules (sugar)	"Demystifying" instrumentation
Enjoyable and valuable: it truly demistify the principle and utility of the polarimeter. I find the instruments the most difficult to learn, to understand, hence I found this experiment a very valuable one to undertake	It's an enjoyable practical to do - it keeps you entertained and you can have a lot of fun with it
	The hands, playing with the polarimeter
The preparations and the methods outlined in the lab manual were neat and easy to follow	Construct the home-made polarimeter
Simple, clear, effective	Simple set-up that allows accurate results

ACELL Workshop – Feedback from Survey A

What, if any, are the notable weaknesses of this experiment?	
Sucrose is difficult to dissolve in cold water, and so a correct concentration reading may be difficult to achieve. Similarly, concentrations may be altered upon transfer of solutions	It's unclear what background students have had in order to answer question 7, using data, slope, and significant figures to calculate [α]
The experiment has the potential to become very tedious - for example, making the sugar solutions and taking measurements	The steps required to complete this exercise are very simple - is there a way to further challenge the students?
Doesn't explain enough of why has the results being achieved (e.g. why does the measured rotation lies in the range of the angles obtained from the experiment)	I feel as if the reason why plane polarised light does rotate is not really explained, i.e., why does it rotate?
Doesn't tie into industry - I don't really know what it would be used for apart from turbidity tests	Make better use of the standard volumetric techniques

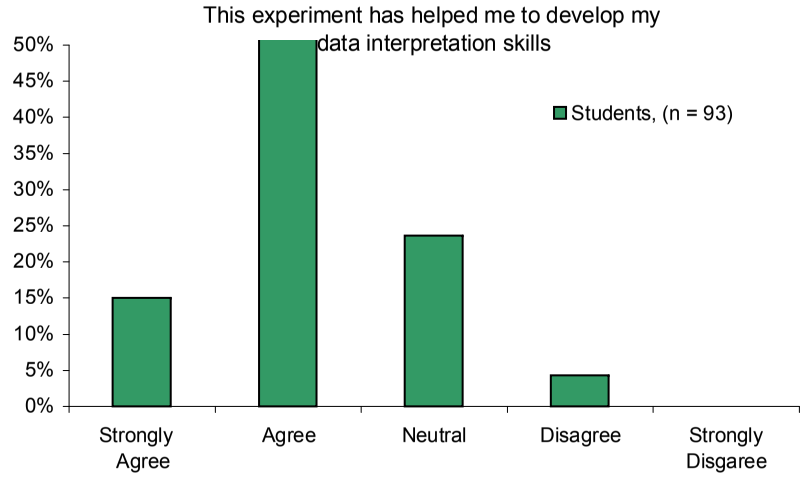
What do you think was the main lesson to be learnt from this experiment?	
How the variable (path length and concentration of solute) affect the measured rotation of plane polarised light	Chiral compounds are indeed optically active, and as a result can bend light passing through them. This can be measured by a polarimeter
Chiral molecules rotate plane polarised light	I have learnt how to construct a polarimeter and anlysed the optical activity of sucrose
Learn how a polarimeter works, and the parameters of using the instrument (concentration and path length)	Chiral molecule has an optical activity which can rotate the plane polarised light
	That concentration and path length affect the degree of rotation
It also demonstrates that a molecule does in fact rotate the plane polarised light	Both concentration of a solution and distance affect the degree of rotation of the light path
That some molecules rotate polarised light	That the extenet of rotation can be measured and used in a variety of ways
How a polarimeter works	I've learnt the relationship between concentration of a substance and its measured rotation

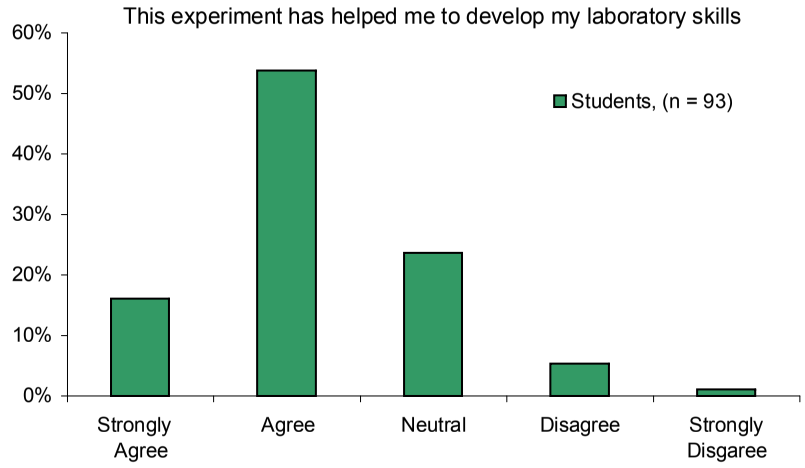
What improvements, if any, do you suggest be made to this experiment?	
Some instruction of placing the cell into and out of the tube as there was some confusion with some students in the best way to do it	Also, address the questions: (1) WHY does the light rotate more when the concentration is greater? and (2) WHY / HOW does the path length affect the polarisation of light?
Look at racemate	Use the polarimeter on a racemic mixture, and see if you get 0° rotation
Compare the results of using a polarimeter on enantiomers of a compound	Explain where it might be used in industry
Perhaps a good brief discussion of the results and errors of the experiments should be conducted after t lab	We can test the enantiomer of the chiral molecule so that we can get the result of the chiral molecule ca rotate the place polarised light in opposite direction
Just include in the background where the skills used and the knowledge learnt would be used in the wor force	d would get the students to analyse some unknown samples - i.e. measure the optical rotation, what is the concentration?
Use six volumetric flasks	Determine the concentration of an unknown sucrose solution by measuring

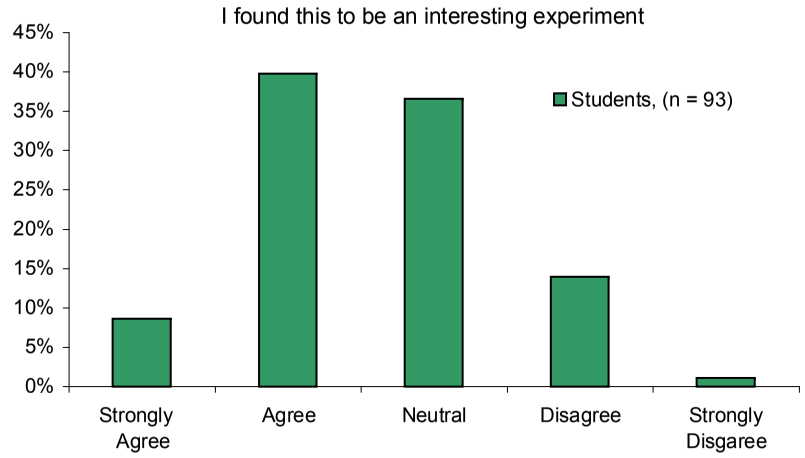
Please provide any additional comments on this experiment here	
An excellent introductory prac, as the materials are not hazardous and the variables examined are clearly separated and highlighted	It was fun, Good Job!

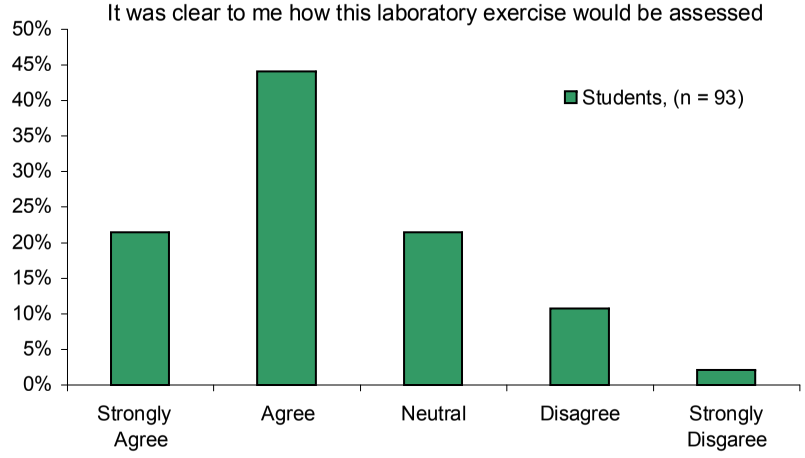
V. ACELL Student Learning Experience (ASLE) Data

Summary of Student Response Data for Experiment: "Investigating the Rotation of Plane Polarised Light Using a Home-Made Polarimeter"









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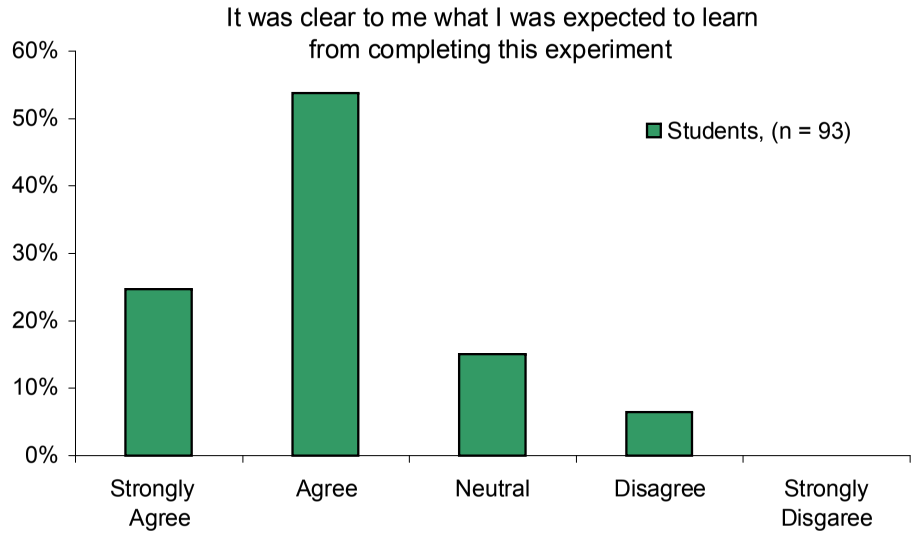

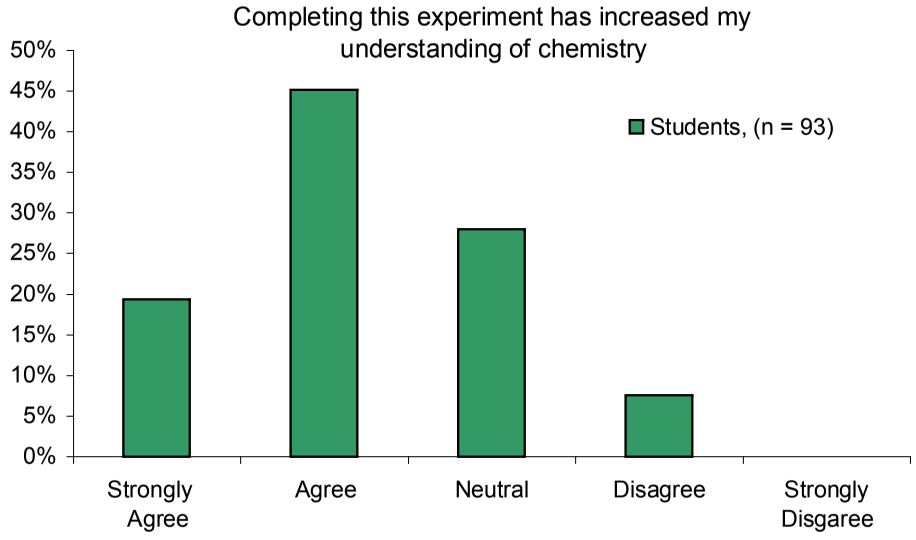

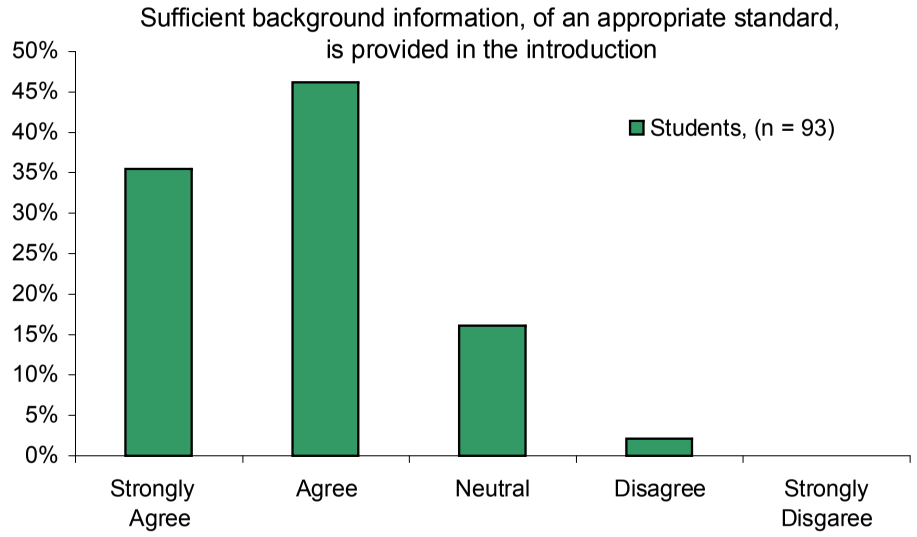

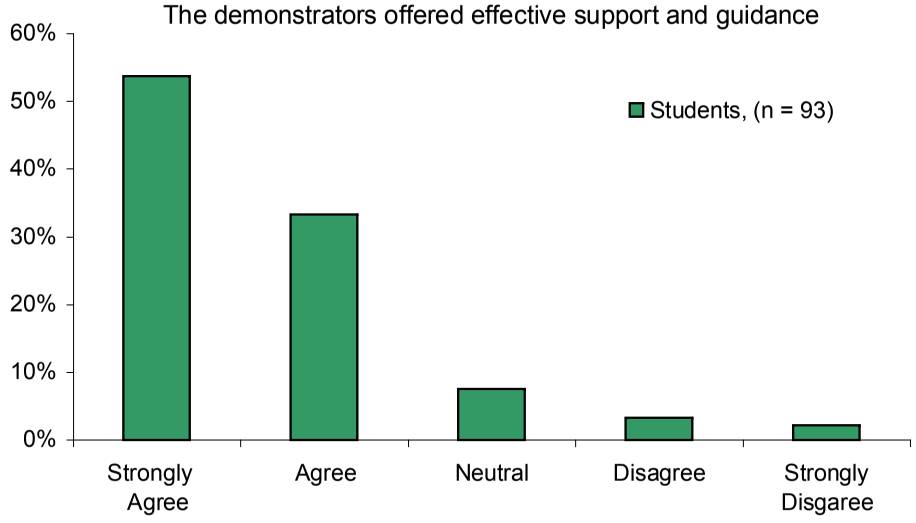

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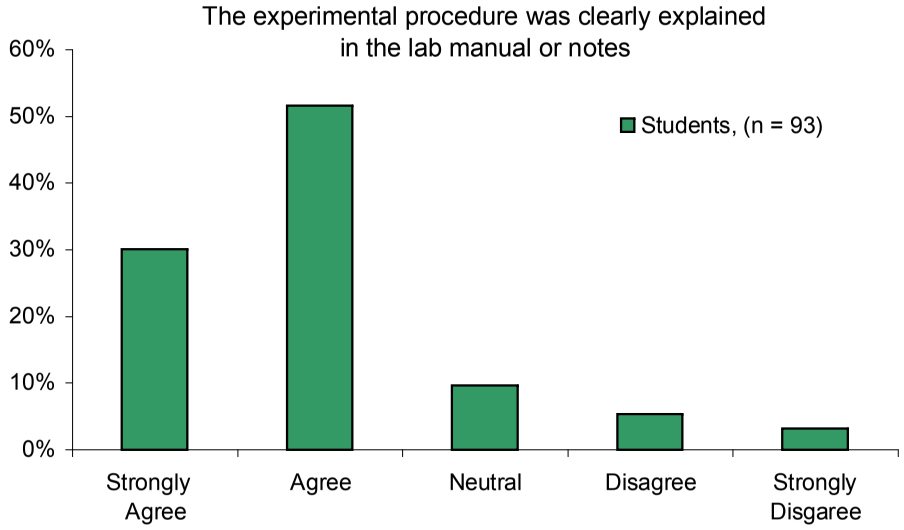
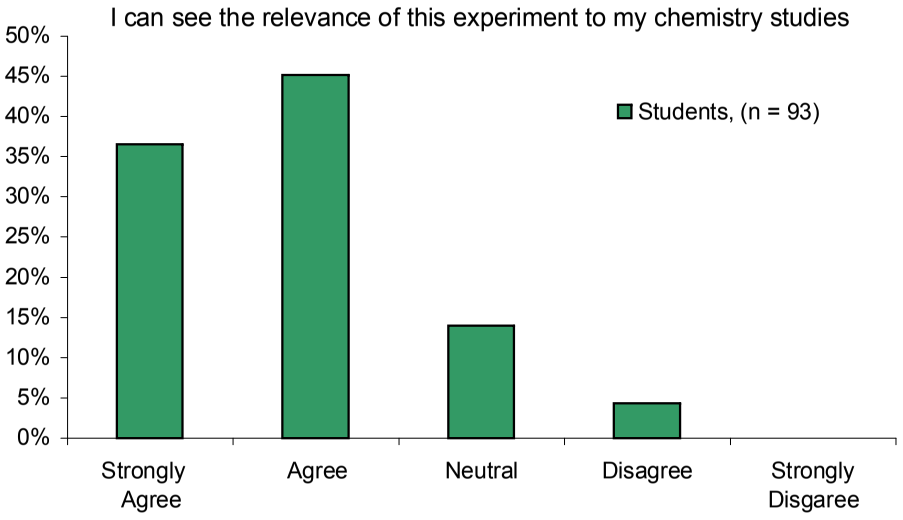
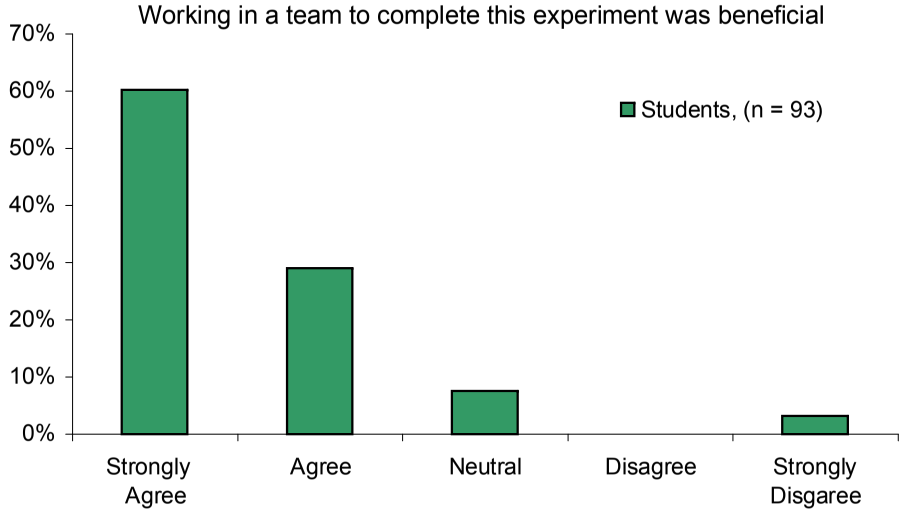
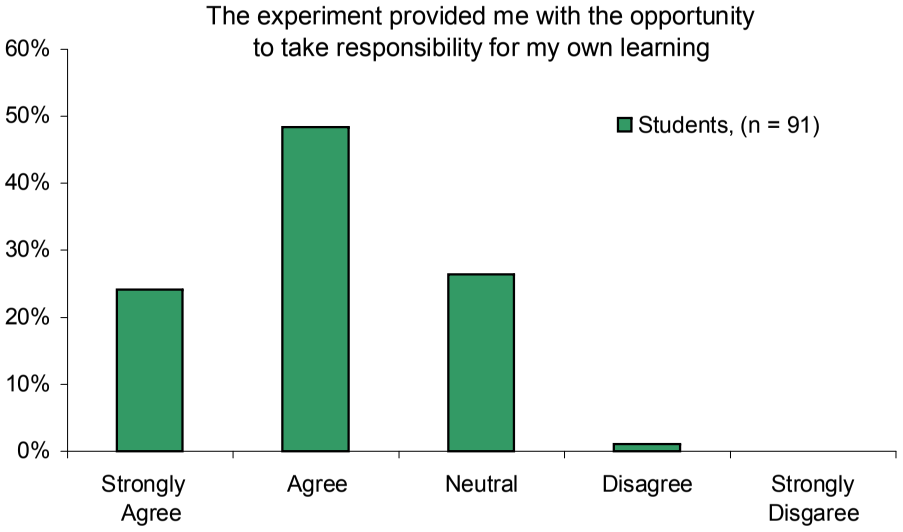
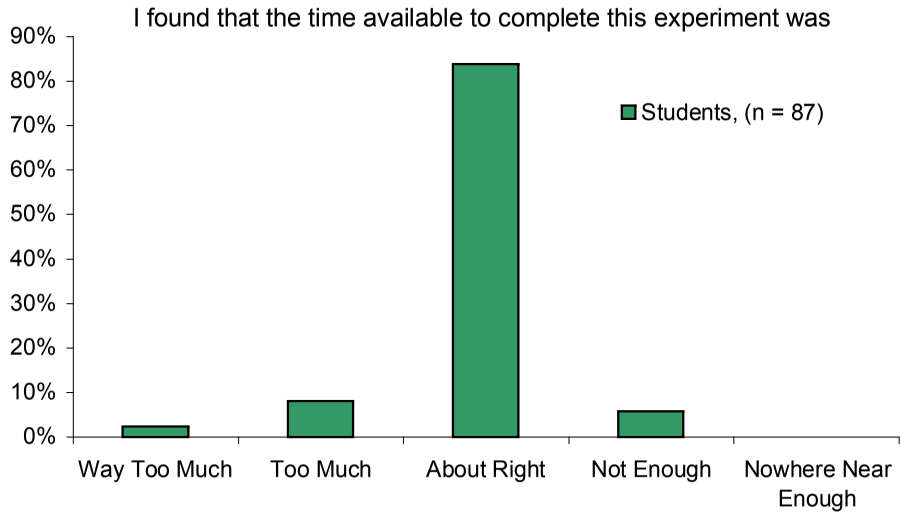


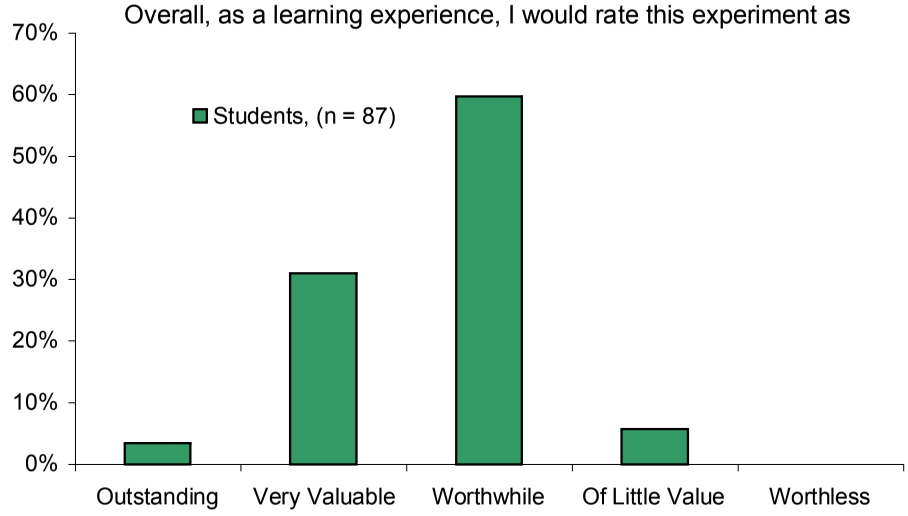






Summary of Student Response Data for Experiment: "Investigating the Rotation of Plane Polarised Light Using a Home-Made Polarimeter"





Summary of Student Response Data for Experiment: "Investigating the Rotation of Plane Polarised Light Using a Home-Made Polarimeter"

Number	Item	Mean	Standard Deviation	% Agree or Strongly Agree
1	This experiment has helped me to develop my data interpretation skills	+0.83	0.73	72.0%
2	This experiment has helped me to develop my laboratory skills	+0.78	0.82	69.9%
3	I found this to be an interesting experiment	+0.41	0.88	48.4%
4	It was clear to me how this laboratory exercise would be assessed	+0.72	0.99	65.6%
5	It was clear to me what I was expected to learn from completing this experiment	+0.97	0.81	78.5%
6	Completing this experiment has increased my understanding of chemistry	+0.76	0.85	64.5%
7	Sufficient background information, of an appropriate standard, is provided in the introduction	+1.15	0.77	81.7%
8	The demonstrators offered effective support and guidance	+1.33	0.91	87.1%
9	The experimental procedure was clearly explained in the lab manual or notes	+1.00	0.96	81.7%
10	I can see the relevance of this experiment to my chemistry studies	+1.14	0.82	81.7%
11	Working in a team to complete this experiment was beneficial	+1.43	0.89	89.2%
12	The experiment provided me with the opportunity to take responsibility for my own learning	+0.96	0.74	72.5%
13	I found that the time available to complete this experiment was	+0.07	0.48	
14	Overall, as a learning experience, I would rate this experiment as	+0.32	0.64	

For items 1 to 12, a +2 (strongly agree) to -2 (strongly disgree) scale has been used, with a 0 (neutral) midpoint - for these items, the ideal response is +2.
For item 13, a +2 (way too much time) to -2 (nowhere near enough time) scale has been used, with a 0 (about right) midpoint - for this item, the ideal response is 0.
For item 14, a +2 (outstanding) to -2 (worthless) scale has been used, with a 0 (worthwhile) midpoint - for this item, the ideal response is +2.

Percentage of students indicating that too much time is available for this experiment	10.3%
Percentage of students indicating that the time available fot this experiment is about right	83.9%
Percentage of students indicating that not enough time is available for this experiment	5.7%
Percentage of students rating this experiment as very valuable or better	34.5%
Percentage of students rating this experiment as worthwhile or better	94.3%