Shifting Towards Inquiry-Orientated Learning in a High School Outreach Program

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Abstract

This paper presents results of an examination the effect of the introduction of inquiry-orientated learning, IOL, activities into the formal education outreach program for senior high school Physics students run by School of Physics at the University of Sydney, 'Kickstart Physics.' This is the flagship outreach program from the Faculty of Science and accommodates approximately a quarter of the total number of students that sit the state Physics exam. The project considered how students arrive at different inquiry-orientated outcomes such as making hypotheses, displaying and interpreting data, validity, reliability, as well as the mental effort reported by the students during the Kickstart workshop. Results from a survey developed for this study show that a significant increase in mental effort was applied by the students in the inquiry-orientated logbook. In addition, the results presented here suggest that the existing, non-modified logbook, based on the current state (NSW) syllabus, has a strong inquiry focus. The methodology was to survey Senior high school students taking part in the Kickstart workshops. Some were given a logbook to accompany the session designed from the NSW Physics syllabus, and some were given a logbook designed around inquiry-orientated learning. The content related to the syllabus for each workshop remained constant.

Context

Universities often offer a range of programs for high school students as outreach activities. These programs have various objectives, including student recruitment. One such outreach program is the Kickstart Physics program run by the School of Physics at the University of Sydney. Previously, program evaluations were focused on the performance of the staff involved and content of the program (Dooley 2010) rather than student engagement, learning outcomes or the inquiry-orientated nature of the workshop.

Kickstart Physics (Kickstart Physics Website 2014) is delivered to predominantly senior high school students in New South Wales, Australia and is designed to complement the Higher School Certificate (HSC) syllabus delivered to year 12 students. Each workshop of 2.5 hours takes the students and their teachers through five experiments related to their syllabus. The workshops have been iteratively designed based on research and best practice with the collaboration from the Sydney University Physics Education group (SUPER) and the Faculty of Science. Kickstart employs postgraduate and undergraduate student tutors to assist with the delivery of the workshops. The student tutors are trained in the delivery of the content, the HSC syllabus, and the use of the demonstrations and experiments.

In 2014, 9,739 students sat the HSC exam for Physics (NSW Board of Studies Website 2014) and 2,253, attended the Kickstart workshops (23%) from across the state of New South Wales. Since the workshops have been running, the number of attendees has slowly risen to be more than double of what it was at the program's inception. Figure 1 shows total number of enrolments. Note that this does not represent the number of unique students since students may attend more than one workshop. The data for 2011 is omitted due to unreliable data.

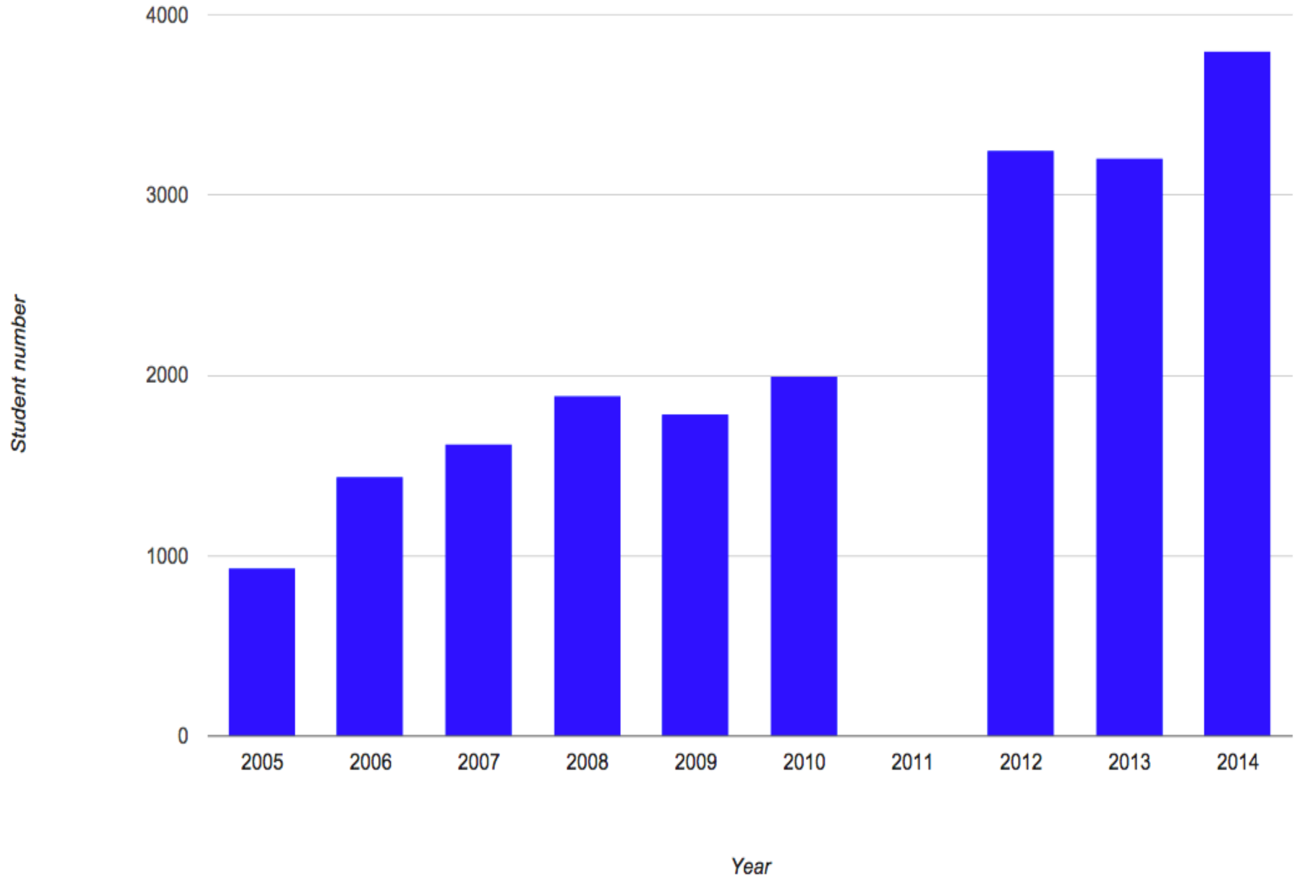


Figure 1. Increase of student numbers attending Kickstart over time

Inquiry in Kickstart

Inquiry as an educational pedagogy underpins all science and with such a large number of students available for survey, this presents an excellent opportunity to gather meaningful data on inquiry-orientated learning and has been briefly investigated with some preliminary results analysed (Gordon, Sharma and Georigou 2014). However, there is a scarcity of papers on inquiry oriented learning in high school science outreach programs.

Consequently, we had to consider, whether incorporating inquiry into Kickstart would be a worthwhile investment of time and how to incorporate inquiry into the short outreach activities. Probing literature, in a synthesis of research on inquiry-based science instruction in schools from 1984 to 2002, Minner, Levy and Century (2010) found 138 papers of adequate quality indicating:

'a clear positive trend favoring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing conclusions from data. Teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques.' (p.474)

From our perspective, the claims made by Minner et al. (2010) would make investing in inquiry-oriented learning in Kickstart worthwhile. But what would the inquiry activities look like given the short time frame within which the Kickstart activities occur?

The critical issue is, how to incorporate inquiry. Inquiry features strongly in tertiary education (Kirkup 2013) and in the NSW syllabus, so is therefore a strong focus in schools (Tamir, Stavy and Ratner 1998). However, there is little incentive for outreach providers to implement inquiry-orientated learning into their programs. This paper examines how a unique environment such as Kickstart Physics might incorporate inquiry-orientated learning

Depending on which type of enquiry, different facets of inquiry need to be considered. Campbell, Abd-Hamid and Chapman (2010) consider framing research questions, designing investigations, conducting investigations, collecting data and drawing conclusions; while work published by the NRC considers questions, data and evidence, analysis, explanations, connections with scientific knowledge, and justification as important. This is in line with the 5E's model of engage, explore, explain, elaborate and evaluate (Bybee 2008) utilised in science teacher education programs in many countries including Australia and the United States of America.

For our experiments, we drew on the above and focused on a concrete set of outcomes relevant to the syllabus and consistent with findings from literature, (Richardson, Sharma and Khachan 2008). This is particularly important for outreach programs of this nature, as these must match the perceived needs of the participating teachers and students. They need to see the immediate value in engaging with outreach activities in senior high school while preparing for a high stakes exam. These were:

- Make a hypothesis
- Design an experimental procedure
- Collect and present data
- Analyse data
- Identify risks
- Relate results to applications
- Comment on validity, reliability and accuracy
- Relate conclusion to experimental aim

These outcomes formed the basis of part of the survey instrument.

The next step is to reduce direct instructions and tutor lecturing and shift the responsibility to the students for making decisions with respect to the listed outcomes as described by Bell, Smetana and Binns (2005). Increasing student involvement in this way has been successful in a number of recent, local programs such as IOL activities in the higher education sector (Familari, Da Silva, Rayner, Young, Cross and Blanksby 2013; Kirkup 2013) and the ASELL in schools project (Yeung, Sharma, Kable and Sutherland 2014). Our work is novel in systematically exploring the incorporation of inquiry into an outreach program.

A mental effort scale effort was also used as a measure for cognitive load (Paas, Tuovinen, Tabbers and Van Gerven 2003). An increase in mental effort can be seen to help students learn through thinking through processes (Hake 1998) as opposed to following instructions. Vosniadou et al. (2001) explain:

> *'Learning is an effortful and mindful process and students should be encouraged to construct their own knowledge and skills through active processing, rather than being passive listeners'* (p.382)

Aims

In exploring how best to include IOL activities in the Kickstart Workshop, we considered how effective the materials were in engaging students by:

- Measuring the reported confidence of students' ability in implementing the outcomes listed in the earlier section
- Measuring the mental effort students were exerting during the activity
- Analysing the use of the redesigned logbooks.
- Assessing student understanding of inquiry

The expected outcomes from the experiment were that the students show an increase in confidence across most, if not all of the identified areas of inquiry, an increase in mental effort over the course of the 2.5 hour workshop and an increase in the use of the redesigned logbooks, and finally, to have the students understand what is meant by the term scientific inquiry.

While the overarching aim is to improve a student's learning outcomes using IOL methods in the workshop, we did not directly measure this in our this study. It would be informative and powerful to measure student learning outcomes related to inquiry however, the tools to do this have not been satisfactorily developed in the literature. This is a worthy aim for future work.

Methods

The existing workshop was originally designed to assist teachers to navigate through the new syllabus (Whymark, Stewart, Sharma and Prosser 2002) at a time where they had very little support or resources. Those resources have since matured and thus the content and structure of the original workshops and logbooks were no longer appropriate. With the experience of a qualified high school teacher, together with the research expertise of the Sydney University Physics Education Research (SUPER) group and the Faculty of Science, the workshops underwent a research based iterative redesign in order to better deliver the content, align the session with best practice and provide useful resources for students and teachers.

The most popular workshops are based on the *Motors and Generators* and *From Ideas to Implementation* core modules, with 57% of participants selecting these modules in 2014. The workshops that the students participated in were chosen by the teachers to align with their students' progress and knowledge. Each student was provided with all equipment, instruction and resources needed.

The study focused on the workshops of the two modules above due to larger sample size, the students had also already completed those topics in class with their teacher. This decision was made for reliability and also to control as many variables as possible and eliminate any bias, while offering students opportunities to demonstrate their understanding of experimentation rather than introduce new content.

The study was carried out during the Kickstart sessions in 2014, which ran either in the morning or afternoon, Monday to Friday. The survey and the study had ethics approval.

Experiment design

The experiment design was to complete a comparative study of student responses from an existing logbook against a modified inquiry-orientated logbook. A sample of n_t=318 students were surveyed from the 2014 Kickstart outreach program with n_i=92 asked to complete the inquiry-orientated workshop and n_e=226 students completed the existing workshop. The students participated with informed consent and were aware that the study would not affect their school assessment.

The changes made to the logbooks made were specifically designed to increase the input of inquiry-orientated pedagogy into the program. A stronger focus on skills and processes replaced textbook-like content. For example, where the existing logbook asked the students to graph some tabulated data, the inquiry-orientated logbook asked students: how would best represent tabulated data? The idea being that the process of interpreting and presenting data is a fundamental scientific skill, but it is also an element that students studying in the HSC are tested on (NSW Board of Studies Physics Syllabus 2002).

Presented here in Figure 2 is an example of the difference between the existing worksheet and inquiry-orientated logbook. Evident is that the existing worksheet is asking students to fill out a table with assistance and guidance from a student tutor. This is an activity that could very easily be completed by a class in their own time and has no real inquiry-orientated learning element present. In the inquiry-orientated logbook, students are asked to construct a disassembled model of an AC induction motor, and then essentially create an experiment method for their process.

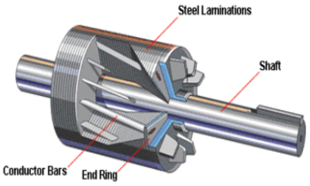
The iterative design can also be seen. In the existing worksheet, we see the instruction "construct from the parts provided, a working AC induction motor." This was included in an earlier version of the worksheet in addition to the comparison table to increase the hands on activity and provide some elements of learning through doing. In the inquiry-orientated logbook, this task has been promoted as the main activity and integrated into a task that is directly related to one of the previously identified scientific skills, in this case, writing an experimental method.

Existing worksheet

AC Induction Motors

Constuct from the parts provided, a working AC induction motor.

Complete the table below for each type of motor.



	Description		
Component	**DC motor**	**Universal Motor**	**AC Induction motor**
Rotor			
Stator			
Commutator **Power supply**			
Physics concept behind motor			
Applications/ Examples			

Inquiry Logbook

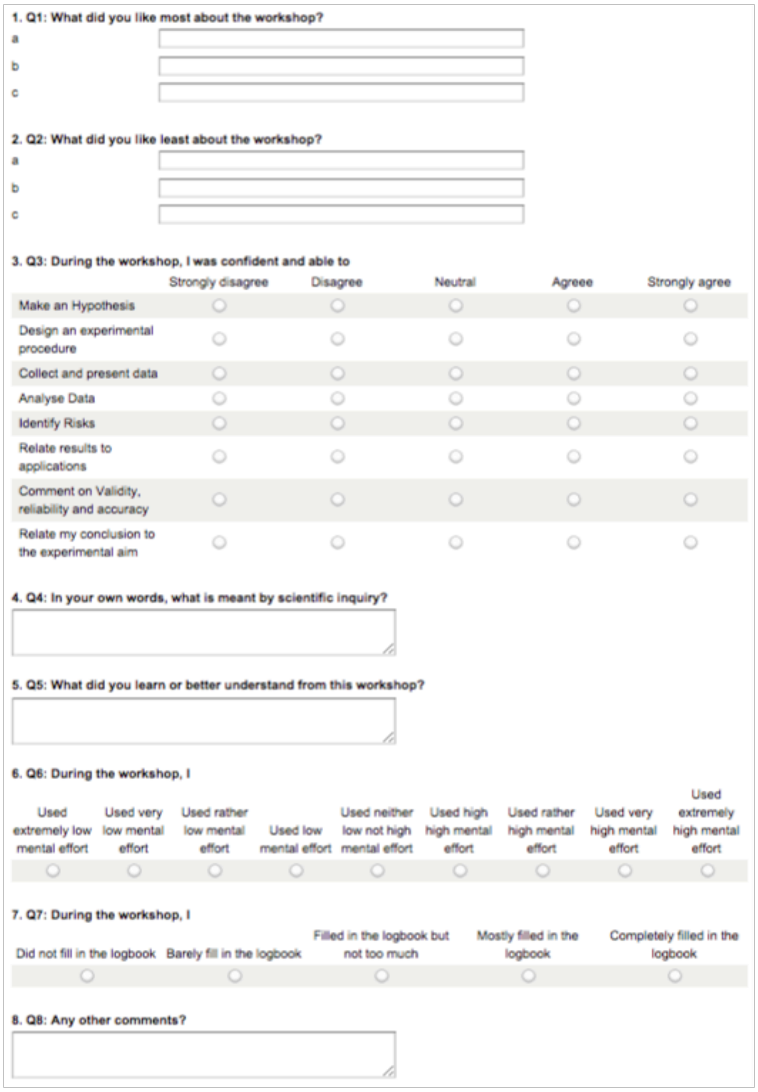
AC Induction Motors

Write an experimental procedure for this construction of these models.

Figure 2. Sample worksheet from the existing and inquiry-orientated logbooks

Procedure and instruments

The worksheets were designed to reduce the information presented where possible by cutting out unnecessary words and instructions and redundant sources of information in place of hands on techniques (Sweller 1998). The casual academic tutors were given a brief introduction and training to the modified logbook and understood the rationale for the project.



1. Q1: What did you like most about the workshop?

a

b

c

2. Q2: What did you like least about the workshop?

a

b

c

3. Q3: During the workshop, I was confident and able to

	Strongly disagree	Disagree	Neutral	Agreee	Strongly agree
Make an Hypothesis	○	○	○	○	○
Design an experimental procedure	○	○	○	○	○
Collect and present data	○	○	○	○	○
Analyse Data	○	○	○	○	○
Identify Risks	○	○	○	○	○
Relate results to applications	○	○	○	○	○
Comment on Validity, reliability and accuracy	○	○	○	○	○
Relate my conclusion to the experimental aim	○	○	○	○	○

4. Q4: In your own words, what is meant by scientific inquiry?

5. Q5: What did you learn or better understand from this workshop?

6. Q6: During the workshop, I

Used extremely low mental effort	Used very low mental effort	Used rather low mental effort	Used low mental effort	Used neither low not high mental effort	Used high high mental effort	Used rather high mental effort	Used very high mental effort	Used extremely high mental effort
○	○	○	○	○	○	○	○	○

7. Q7: During the workshop, I

Did not fill in the logbook	Barely fill in the logbook	Filled in the logbook but not too much	Mostly filled in the logbook	Completely filled in the logbook
○	○	○	○	○

8. Q8: Any other comments?

Figure 3. Survey response form

To investigate inquiry we considered a number of inquiry-orientated outcomes, (Richardson et al. 2008) as listed in dot-points in the Inquiry in Kickstart section of this paper (Making a hypothesis, analysing data, etc.). These outcomes informed the design of the survey instrument.

Figure 3 shows the survey instrument that consisted of some open-ended responses that were coded in the analysis, as well as some Likert scale responses. The survey was delivered to the participating students in paper form and then entered into a survey monkey database for data analysis. The survey took approximately 5 minutes to complete at the end of the workshop.

Results and discussion

Figure 4 is the strongest result from the experiment, shows the responses to a validated Likert scale (Muller 2008). An analysis of the t-test of the mean of these two responses shows a statistical significant difference from the existing to the inquiry-orientated logbooks with p=0.03.

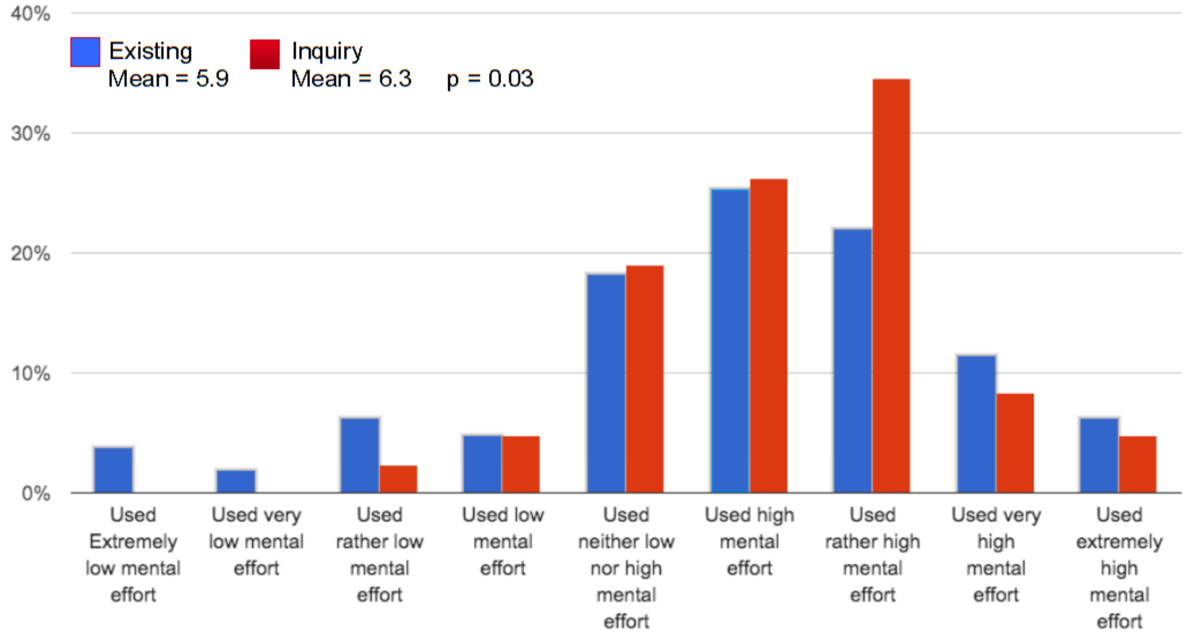


Figure 4. How much mental effort was used in the workshop?

This result indicates that the more inquiry-orientated design is present in the logbook, the more the students' work at the experiments. This extra mental effort is thought to translate into deeper learning for students (Hake 1998). An encouraging result was that no student completing the inquiry-orientated logbook reported using anything less than rather low mental effort.

From the Likert scale responses on the survey, the students reported that they were more confident in making comments on the reliability, validity and accuracy after completing the inquiry-orientated workshop than the existing workshop. This is encouraging as the inquiry-orientated workshop directly asks the students to consider these scientific concepts, without mentioning the terms specifically. From Figure 5, the red indicates a positive response in the Likert scale (agree = 4, strongly agree = 5) on the inquiry-orientated logbook, and the blue indicates the same item from the existing logbook. The white and yellow indicate a neutral response in the inquiry-orientated and existing logbooks respectively, and the black indicates a negative response: strongly disagree = 1, disagree = 2, Neutral=3 (Sharma, Mendez, Sefton and Khachan 2014). No large difference in responses could be seen in the examples of collecting and presenting data, which was indicative of most of the other responses shown in figure 2. These results align with some of the objectives of the project. There is evidence that changes made to the logbook have promoted skills in the specific example of commenting on validity, reliability and accuracy.

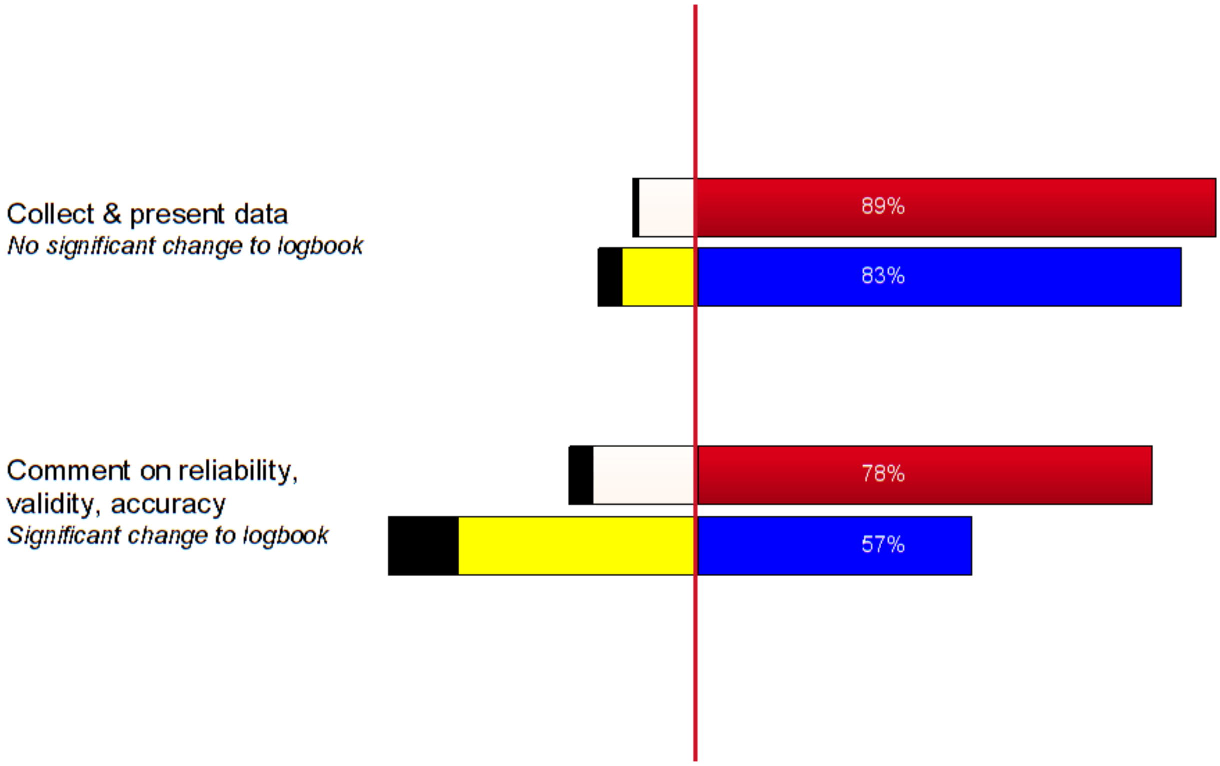
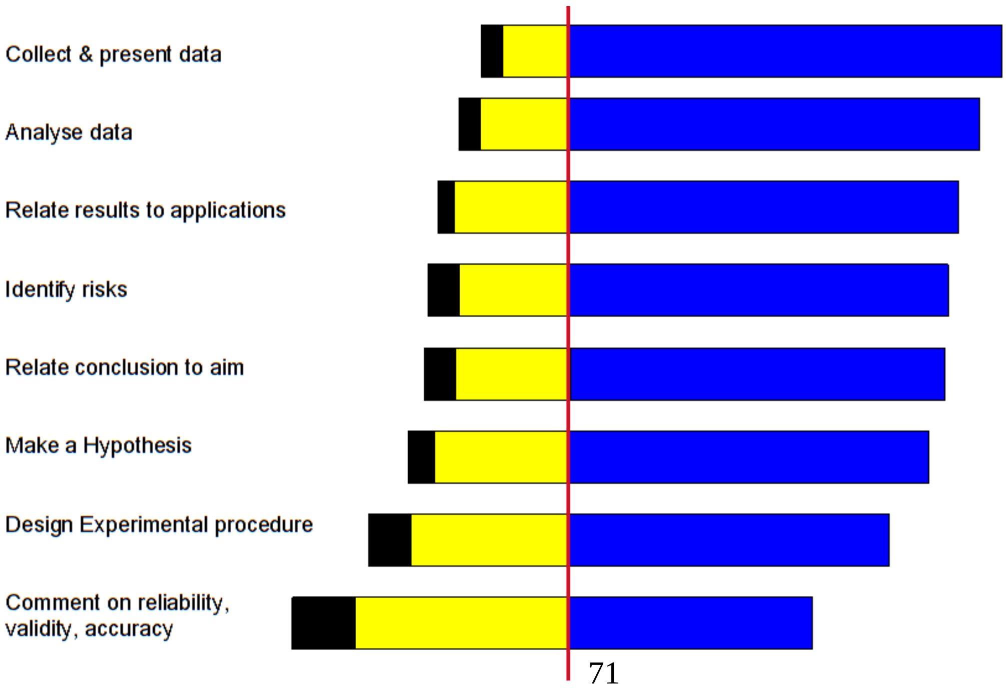


Figure 5. Frequency (%) from selected Likert Responses

In Figure 6, the results from the ranking of question 3 are presented in order of descending frequency of responses from the responses completed by students completing the existing worksheet. We can see a general shift in positive responses from the inquiry-orientated workshop, but overall we can generalise that both the existing logbooks and the inquiry-orientated logbooks promote inquiry-orientated thinking with very positive responses. This aligns with the fact that the logbooks have previously undergone an iterative process towards IOL.



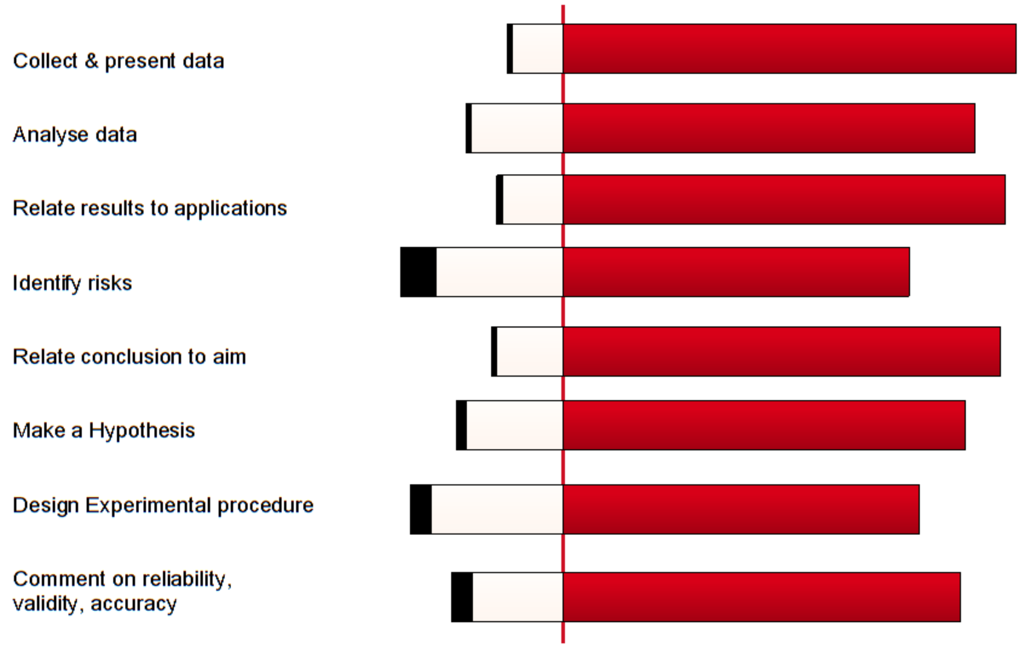


Figure 6. Frequency (%) of Likert responses to identified elements of scientific inquiry ordered by the frequency of responses from the existing worksheet

When asked in the survey about the term scientific inquiry, it became clear that the students completing the inquiry-orientated logbook had a clearer understanding of the term than those who completed the existing logbook. The column labelled scientific inquiry in Figure 7 represents those students who simply restated the question of “In your own words, what is scientific inquiry?” From the graph, we see that the students that completed the inquiry-orientated worksheet were far more likely to define scientific inquiry with a thought-out response for example, “asking a question, design a method to observe data to address this question,” rather than simply restating the question From the responses, “to enquire about science.” This was an unexpected result from the modification of the logbooks.

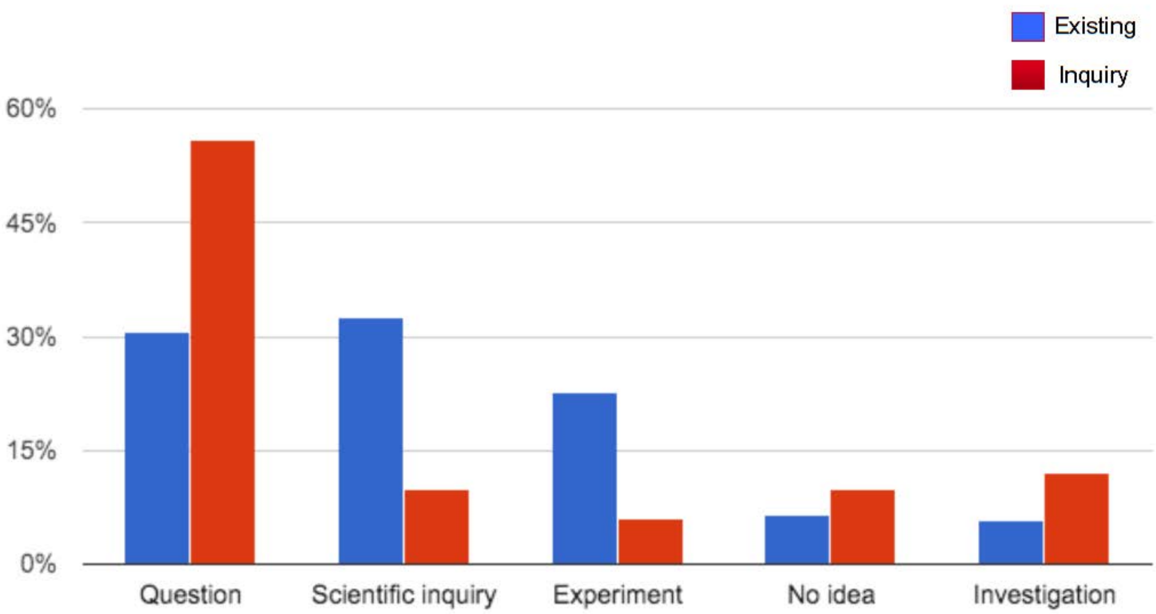


Figure 7. In your own words, what is meant by scientific inquiry?

Conclusions and implications

The principal conclusion from this project is that it is indeed possible to have meaningful IOL in a 2.5 hour workshop with minimal tutor training for thousands of students by research backed inquiry-orientated logbooks as seen by student participant responses to modified logbooks. Further indications from this project will form the aims and hypotheses for subsequent research projects.

Implications for scientific skills

Students attending the Kickstart workshops generally report to be confident in the identified scientific skills. However, more focus on skills such as commenting on reliability, validity and accuracy will be considered in future studies in order to better measure the observations. Future studies will consider this question further in order to collect more data and insights into the details of the level of confidence in specific scientific inquiry skills in high school students.

Implications for mental effort

From these results, further modification of the logbooks will take mental effort into account and will endeavour to ensure that a challenge is presented to the students during the workshop in order to maximise the benefits they gain from the workshop through the increase of mental effort. Care will need to be taken to not make the mental effort too great so that the tasks become too difficult.

This will be a delicate balance between offering a challenge while keeping to the syllabus and time constraints. The successful approach seems to be to remove verbal and textual instruction and replace it with hands-on activities aligning with previous research. Further investigation into mental effort in an outreach program will seek to further gather more data on this.

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References

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher, 72*(7), 30-33.

Bybee, R. (2008). Teaching Science as Inquiry. In L.W. Trowbridge, R. W. Bybee, & J. C. Powell (Eds.), *Teaching secondary school science: Strategies for developing scientific literacy* (pp. 50-57). Upper Saddle River, NJ: Merrill.

Dooley, P. (2010). Building a Successful Outreach Program. *Proceedings of the 16th UniServe Science Annual Conference* (pg.122). Sydney, Australia: University of Sydney

Campbell, T., Abd-Hamid, N. H., & Chapman, H. (2010). Development of instruments to assess teacher and student perceptions of inquiry experiences in science classrooms. *Journal of Science Teacher Education, 21*(1), 13-30.

Familari, M., Da Silva, K. B., Rayner, G., Young, J., Cross, A., & Blanksby, T. (2013). Scientific inquiry skills in first year biology: building on pre-tertiary skills or back to basics?. *International Journal of Innovation in Science and Mathematics Education, 21*(1), 15.

Gordon, T., Sharma, M., & Georigou, H. (2014). Inquiry based learning in a university outreach program. In

Proceedings of the Australian Conference on Science and Mathematics Education (pg. 28). Sydney, NSW: University of Sydney

Hake, R. R. (1998). Interactive-engagement vs. traditional methods: A six thousand-student survey of mechanics test data for introductory physics courses, *American Journal of Physics, 66(*1), 64-74.

*Kickstart Physics (*2014). Retrieved April 29, 2015, from http://sydney.edu.au/science/outreach/high-school/kickstart/physics.shtml

Kirkup, L. (2013). Inquiry-oriented learning in science: Transforming practice through forging new partnerships and perspectives. *ALTC National Teaching Fellow Final Report for the Australian Government Office for Learning and Teaching*. Retrieved April 29, 2015, from http://www.olt.gov.au/system/files/resources/Kirkup_NTF_report_2013_2.pdf

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474-496.

Muller, D. (2008) Designing effective multimedia for physics education. (Doctoral dissertation). University of Sydney: Sydney, Australia.

NSW Board of Studies (2014). Retrieved February 6, 2015, from http://www.boardofstudies.nsw.edu.au/news-media/media-guide-2014/numbers.html

NSW HSC Physics syllabus (2002). Retrieved February 6, 2015, from http://www.boardofstudies.nsw.edu.au/syllabus_hsc/pdf_doc/physics-st6-syl.pdf

Paas, F., Tuovinen, J. E., Tabbers, H. & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist*, *38*(1), 63-71.

Richardson, A., Sharma, M. D., & Khachan, J. (2008). What students learning in practicals? A cross sectional study in a university physics laboratories. *CAL-Laborate International*, *16*, 20-27.

Sharma, M. D., Mendez, A., Sefton, I. M., & Khachan, J. (2014). Student evaluation of research projects in a first year physics laboratory, *European Journal of Physics*, *35*, 2.

Tamir, P., Stavy, R., & Ratner, N. (1998). Teaching science by inquiry: assessment and learning. *Journal of Biological Education*, *33*(1), 27-32.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction*, *11*(4), 381-419.

Whymark, A., Stewart, C., Sharma, M. D., & Prosser, M. (2002). Does the new HSC physics syllabus let students think differently about their physics knowledge differently? *Proceedings of the 15th Australian Institute of Physics Congress* (pp. 265-267). Sydney, NSW: University of Sydney

Yeung, A., Sharma, M., Kable, S., & Sutherland, L. (2014). A tool for helping educators evaluate the level of inquiry in laboratory activities. *Proceedings of the Australian Conference on Science and Mathematics Education* (pg. 97). Sydney, NSW: University of Sydney