An Inquiry-Based Approach to Laboratory Experiences: Investigating Students' Ways of Active Learning

Maria B. Parappilly[a], Salim Siddiqui[b], Marjan G. Zadnik[b], Joe Shapter[a], and Lisa Schmidt[c]

Corresponding author: maria.parappilly@flinders.edu.au
[a]School of Chemical and Physical Sciences, Flinders University, Adelaide SA 5001, Australia
[b]Department of Imaging and Applied Physics, Curtin University, Bentley WA 6845, Australia
[c]Centre for University Teaching, Flinders University, Adelaide SA 5001, Australia

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Abstract

It is a common perception amongst students (and faculty) that traditional recipe-based laboratory experiences are generally boring, non-interactive and non-engaging. As a result, such laboratory sessions are unlikely to promote higher order thinking and learning. As a part of the national SaMnet (Science and Mathematics network of Australian University Educators – see www.SaMnet.edu.au) project, we have developed an "inquiry-based" approach to learning in laboratories, and introduced laboratory experiences which are designed to equip first year physics students with the concepts and skills required to plan and carry out an experiment to investigate a particular problem. Our aim was to motivate and stimulate students' interest, so that they explore experimental activities and design their own experiments. We implemented inquiry based laboratory activities for non-physics majors in semester 2, 2012 at two Australian universities. The students were given five traditional and one Inquiry-based Laboratory and this paper reports the student perceptions of the new experience. Students felt they had to do a lot of thinking and analysing for inquiry-based reports and believed that they learnt more in the inquiry-based laboratory than the recipe-based laboratory. We also found that student marks either improved (for laboratory reports) or remained the same (for related examination questions), and conclude that inquiry-based laboratories at worst do not negatively impact on student performance and may actually benefit student learning.

Introduction

Laboratory sessions are an integral part of most science courses and the reasons for having them include: engaging students, converting theory into practice, affirming and illustrating concepts, gaining technical expertise, data and uncertainty analysis, report writing and research skills development. However, none of these outcomes will be achieved just because the student attended a laboratory class – the design of the laboratory session is critical and each design will lead to different outcomes. Two major design types are the traditional recipe-based and the more challenging inquiry-based (IB) laboratories. IB experiments are usually designed to introduce independent thinking and creative problem solving skills, compared to recipe-based laboratories, which are used largely for the confirmation of concepts (Domin, 1999). For example, a recipe-based laboratory will provide the students with all of the steps they need to take to complete the practical, and while this will give them the chance to focus on technical expertise and analysis, it does not engage them in the experimental design process. In comparison, IB laboratories incorporate the design process into the session. Advocates of IB laboratories argue that such laboratories promote conceptual understanding, encourage students to explore alternate approaches to investigate a problem, critically reflect on their experiences, and take charge of their own learning (Etkina, Karelina, Ruibal-Villasenor, Rosengrant, Jordan, & Hmelo-Silver, 2010; Abraham 2011). The Boyer Commission (2009: p17) contended that

> *'The basic idea of learning as inquiry is the same as the idea of research; even though advanced research occurs at advanced levels, undergraduates beginning in the freshman year can learn through research'*

Zwickl, Finkelstein, and Lewandowski (2003) argue that guided inquiry laboratories engage students in a sequence of scientific practices that parallel those of an expert researcher. As the experimental results are unknown, students are exposed to the authentic research process (Weaver, Russell, & Wink, 2008). Students themselves report that they have to do a lot of thinking and analysing when completing IB laboratory reports (Chatterjee, Williamson, McCann & Peck, 2009). Healey (2005) recognised the need for engaging students in undergraduate research and found that inquiry is one of the most effective ways to help students to begin to think like a physicist, historian or engineer, and to contribute towards the graduate attribute skills. This approach also falls within the domains of the Threshold Learning Outcomes (TLOs) for science recently published by the Australian Learning and Teaching Council (ALTC)-Learning and Teaching Academic Standard Project Report by Jones and Yates (2011) which are expected to introduce major curriculum reforms at Australian universities. Marshall and Dorward (1997) suggest that university Physics educators with introductory physics teaching responsibilities consider the importance of including IB exercises into their courses. Within the Australian context, a recent the ALTC-National teaching fellowship report (Kirkup, 2013) highlights the transformation of practices towards inquiry-oriented approaches to learning in the undergraduate science curriculum in Australia. See www.iolinscience.com.au for the details of the activities and case studies.

IB laboratories are situated within constructivist learning theory in which the learner is the creator of understanding. This theory is based on the works of Vygotsky, Piaget, and Dewey (Stewart, 2012) and suggests that for learning to occur, students need to be actively engaged in their learning and have the time to interact with the concepts encountered in the laboratory and reflect on their learning (Tobin, 1990). However, several studies had shown that often the students and the teacher are preoccupied with technical and manipulative details that consume most of their time and energy. Such preoccupation seriously limits the time they can devote to meaningful, conceptually driven inquiry (Hofstein, & Lunetta, 2004). Another concern raised about IB laboratories is based on the neuroscience of memory. Kirschner, Sweller, and Clark (2006) argue that learning requires transformation of long-term memory and if a students' working memory is consumed with problem solving, then information is unlikely to be stored in long-term memory. Therefore, students need to possess foundational knowledge before applying that knowledge in the research context. This theory implies that students should do recipe-based laboratories first and only tackle IB laboratories after they have the knowledge and understanding of the concepts contained in the laboratory.

A resolution to the recipe-based vs inquiry-based debate may lie with scaffolding students' development and in this respect, Willison and O'Regan's (2007) Research Skill Development (RSD) Framework provides a conceptual framework for thinking about this. It is structured around gradually increasing student autonomy, for example students progress from a highly prescribed state, "Collect and record required information or data using a prescribed methodology from a prescribed source in which the information/data is clearly evident," to greater autonomy, "Collect and record required information/data from self-selected sources using one of several prescribed methodologies," to independence, "Collect and record self-determined information/data from self-selected sources, choosing or devising an appropriate methodology with self-structured guidelines." (Note, the RSD framework describes more stages in between and more facets of research – see www.rsd.edu.au for details). Increasing student autonomy is also reflected in the spectrum within IB laboratories from guided-inquiry to open-inquiry. Therefore, the issue may not be whether recipe-based or IB laboratories are 'better' but rather when each is most appropriate in the curriculum, the stage of student development, and the stated objective. This paper reports on the outcomes of a trial of an IB laboratory practical at two different universities, and therefore two different curricular and developmental contexts, and provides insight into how the context can affect the perceived effectiveness of the laboratory.

Our aim is to arouse students' interest and engage them with the physics content, where they will explore experimental activities and design their own experiments. IB experiments provide students with an opportunity to become the 'driver' and designer of experimental activity. By investing more effort, they gain a greater ownership of their learning (Horowitz, 2003; Newton, Tracy, & Prudente, 2006). Students will formulate their own questions, or reconcile unexpected results and lead them to active learning. Inquiry based experiments are conducted to develop understanding of a key concept, not merely to check "what works." It will enhance students thinking skills and they will better understand what and why they are doing the investigation (Etkina, & Van Heuvelen, 2007). Design experiments ideally result in greater understanding of learning theory behind the experiment as students need to provide their justification for their method and write comments on the outcome of the final results. Etkina et al. (2010) emphasise that when students are engaged in the design of experiments, they not only develop scientific abilities, but also use them without prompts and scaffolding when transferred to new tasks. A range of other studies also demonstrate the usefulness of such design experiments in engaging students and in promoting their learning (Bell & Linn, 2000; Gallagher, Stepien, Sher, & Workman, 1995); Kolodner, 2002). In an attempt to provide more stimulating and engaging learning experiences, we have introduced IB laboratory activities. This action-learning project, which is supported by SaMnet (Science & Mathematics Network of Australian University Educators), was implemented at Flinders and Curtin Universities in 2012.

Methodology

We implemented an IB laboratory on the topic of Radioactivity for non-physics majors in semester 2, 2012 at both Flinders and Curtin universities. Students were given five recipe-based laboratories and an IB laboratory. To be in phase with the topic delivery at Flinders, we offered this IB laboratory as a third laboratory whereas at Curtin University (due to the historically developed sequence of the unit) this laboratory was scheduled as the last laboratory, giving students relatively more time to develop their basic experimental and reporting skills. This difference in timing of the IB labs at the two universities was unavoidable, but may provide useful information about the optimal timing for introduction of such laboratories.

At both universities content-specific reading materials on Radioactivity and smoke detectors were given before the laboratory to help students acquire prior knowledge to design their own experiment incorporating innovation and experimental techniques. To gauge students' prior knowledge of Radioactivity, we distributed a pre-laboratory questionnaire before the commencement of laboratory.

Four different topics related to radioactivity measurements were posted online for students to choose from. They were:

1. Investigate the properties of alpha, beta and gamma radiation for example using radon measurement. How can you differentiate between these three types of radiation? What precaution can you take to minimize the radiation exposure hazard from a radiation source?

2. Investigate the random nature of radiation emission, the exponential behaviour of nuclear decay and half-life concepts, and applications in various industries such as biomedical sciences and nuclear medicine. How can you measure the half-life of an unknown radioactive sample?

3. How can you measure absorption of radiation in metals and non-metals, such as lead, aluminium and common household materials, such as timber, tiles, bricks, rubber, glass, perspex, water? Discuss how this information can be used in shielding against radiation. Comment why different materials have different absorption abilities.

4. Investigate use of radioactive materials in various industries, such as health, mining, and in household items (e.g. smoke detector). Describe how a household smoke detector works. How does radiation vary as a function of distance? Are there other types of smoke detractors which do not use radioactive substance? Compare advantages and disadvantages of both types.

First year, non-physics major students were asked to select one of these topics to investigate? the properties of radioactive materials and design an IB laboratory activity. Students were required to research background information from various sources. To develop students' skills in critical evaluation, they were required to synthesise the gathered information, to design and undertake the experiment in a safe manner to test their hypothesis.

At Flinders, two weeks before the delivery of the IB laboratory, a focus group was held to trial the laboratory. The formation of the focus group was put together by inviting students to participate via Flinders Learning Online (FLO) discussion forum. The focus group, consisting of four students, was designed to a) assess how an IB laboratory might be useful for students to investigate some of the principles they learn in the lectures rather than simply following a recipe to produce results and back up basic principles, b) gauge their initial response to the experiments, and c) provide feedback as to how to better present the IB laboratories to all the students in the topic.

In each laboratory there were three stations, each containing two Geiger counters along with the smoke detectors and radioactive cobalt, strontium and americium sources. During these laboratory sessions, students worked in small groups of two. For the students performing activity 2 (the half-life laboratory), radioactive silver coins were prepared during the lab. The source of silver for this activity 2 was an old 50 cent coin. Prior to 1969, the Australian 50 cent piece was composed of 80% silver and 20% copper. During the session, a number of silver coins were irradiated in a neutron bath and then placed in a holder on each bench for the group by the lab technician. We have found that for each lab session, measuring the radioactivity of the smoke detector and half -life of silver coins were the most popular activities. We observed that student groups were engaged in the process of designing, testing and writing their own conclusions. The level of interest in this new approach is highlighted in that fact that even after finishing the lab session, some students chose to continue to work on extra activities. The marking scheme for the IB laboratory focussed on students demonstrating that they could design an experiment which tested their aims, regardless of whether the experiment worked or not. This provided the students with a large amount of freedom in deciding how to approach/design the IB laboratory. At the conclusion of the laboratory activity, students were required to present a written laboratory report for assessment.

This project has ethics approval, Flinders (Project Number: 5757 SBREC) and Curtin (Project Number: SMEC-14-13).

Findings and Discussion

The key question to evaluate the effectiveness of the new laboratory was: What are the students' attitudes and perceptions towards IB practicals compared to traditional, verification practicals? The evaluation of the IB practical involved students completing a semantic differential survey (Chatterjee, Williamson, McCann & Peck, 2009) consisting of 8 statements (see Table 1 below) about their attitudes and perceptions towards the IB experiments. For the semantic differential survey at Flinders, the scale used was 1-2-3-4-5. Students circled 1 or 2 if they had a strong agreement or agreement respectively with the left statement, circled 5 or 4 if they had strong agreement or agreement respectively with the right statement, or circled 3 if they were neutral to statements on either side. For the data analysis and for the calculation of <x> we have assigned the value 1 for agreement with the right statement, 3 for neutral and 5 for agreement with the left statement.

In general, students agreed that they like IB laboratories (69%) (Table1). In terms of the length of time required for IB lab, 50% of the students agree with the statement that it takes more amount of more time to complete IB laboratory reports (Table 1). The result for statement 3 may support the findings of Laws et al. (1995) who reported that female students found time demands of activity-based physics lab were unreasonable, though we did not collect data on a gender basis. The analysis of the responses to statement 4 is of particular interest to us, since it tested the effectiveness of IB laboratory to promote higher order thinking skills.

A high proportion of the students (79%) felt that they have to do lot of thinking and analysing for IB reports and 63% of students believe that they do learn more with inquiry-based than compared to recipe based laboratories. Responses to statement 5 indicate that while 62% students agree that IB based laboratories are fun to do there is 25% disagreement with this statement and 13% of students chose neutral. Results show that 25% students liked it better when they had to follow procedures already given in the laboratory manual where as16% students were neutral about this. For statement 6, 59% like to design their own procedure to do the IB laboratories.

Table 1: Distributions of Results of the Semantic Differential Survey–Flinders.

	Left Statement	Agreement with Left Statement, %	Neutral %	Agreement with Right Statement, %	Right Statement	Mean (SD) Total N = 32
1	I like inquiry laboratory.	69	3	31	I do not like inquiry based laboratory.	2.18 (1.79)
2	Inquiry laboratories are easy to do.	40	13	47	Inquiry laboratories are difficult to do.	3.12 (1.86)
3	It takes a smaller amount of time to complete the inquiry laboratory reports.	18	41	50	It takes a larger amount of time to complete the inquiry laboratory reports.	3.43 (1.47)
4	I have to do a lot of thinking and analysing for doing the inquiry-based laboratory reports.	79	6	15	I do not have to do a lot of thinking and analyzing for doing the inquiry based laboratory reports.	1.75 (1.48)
5	Inquiry laboratories are fun to do.	62	13	25	Inquiry laboratories are not fun to do.	2.25 (1.71)
6	I like to come up with my own procedures for doing laboratories.	59	16	25	I like it better when I have to follow the procedures given in the lab manual	2.31 (1.70)
7	I would choose to do an inquiry-based lab over a recipe-based lab	48	19	33	I would choose to do a recipe-based lab over an inquiry-based lab	2.75 (1.78)
8	I personally think that I learn more with inquiry based labs	63	19	21	I personally think that I learn more with inquiry based labs	2.18 (1.64)

This attitude is also reflected in the Curtin study (Table 2). However, only 48% of students prefer IB laboratory over recipe based laboratories (statement 7) while 19% students were neutral and 33% prefer to have a recipe-based laboratory. Overall, attitudes were positive toward IB laboratories.

At Curtin the survey instrument was modified as a ranking questionnaire, see Table 2 below. Statements 1 to 8 requiring students to choose a response from 0 (fully disagree) to 3 (fully agree). Table 2 shows the results from the survey concerning statements 1 to 8 from the Curtin study. Results indicate that 84% students, of the 32 students who responded, liked IB laboratory. At Curtin, IB laboratory was offered as the last (fifth) laboratory (compared to third at Flinders) and by that time students had gained further basic laboratory skills.

Table 2: Survey response to Left Statements 1 to 8 from Curtin Study, N=32.

	Statement	Fully Agree %	Agree %	Disagree %	Fully Disagree	Agreement with the statement, % Total N = 32	Disagreement with the Statement, %
1	I like inquiry based laboratories.	21.9	62.5	6.3	9.4	84.4	15.6
2	Inquiry laboratories are easy to do.	9.4	62.5	28.1	0.0	71.9	28.1
3	It takes a smaller amount of effort to complete the inquiry-based laboratory reports	21.9	62.5	15.6	0.0	84.4	15.6
4	I have to do a lot of thinking and analysing for doing the inquiry-based laboratory reports	21.9	40.6	34.4	3.1	62.5	37.5
5	Inquiry laboratories are fun to do.	25.0	56.3	15.6	3.1	81.3	18.8
6	I like to come up with my own procedures for doing laboratories	15.6	43.8	34.4	6.3	59.4	40.6
7	I would choose to do an inquiry-based laboratory over a recipe-based laboratory	31.3	37.5	28.1	3.1	68.8	31.3
8	I personally think that I learn more with inquiry-based laboratories.	35.5	48.4	16.1	0.0	83.9	16.1

As this was the 5th and last lab for Curtin students, many chose not to do it as the students were only required to do 4 out of the 5 labs. This accounts for the N=32 compared to an enrolment of over 200 students. For statement 4, 63% of students agree that they have to do a lot of thinking and analysing for IB laboratories. So from these positive results from both studies, we can affirm that the IB laboratory promotes higher order thinking skills. For statement 5, 81.3% of students enjoyed IB laboratories, which may be explained by their involvement in designing the laboratories. Both studies show that students felt that they learnt more with IB laboratories. This is because they are involved in reading background knowledge which improves their scientific knowledge. Moreover, the focus of inquiry-based approach is on the student as a learner. This result is consistent with the findings of Marshall and Dorward (2000) who reported that the implementation of limited IB laboratory exercises increased student understanding of the concepts contained in the exercise. Both study results are consistent with Chatterjee et al.'s (2009) findings about guided IB laboratories, which are that while students may not see IB laboratories as fun, they perceive that they learn more from them.

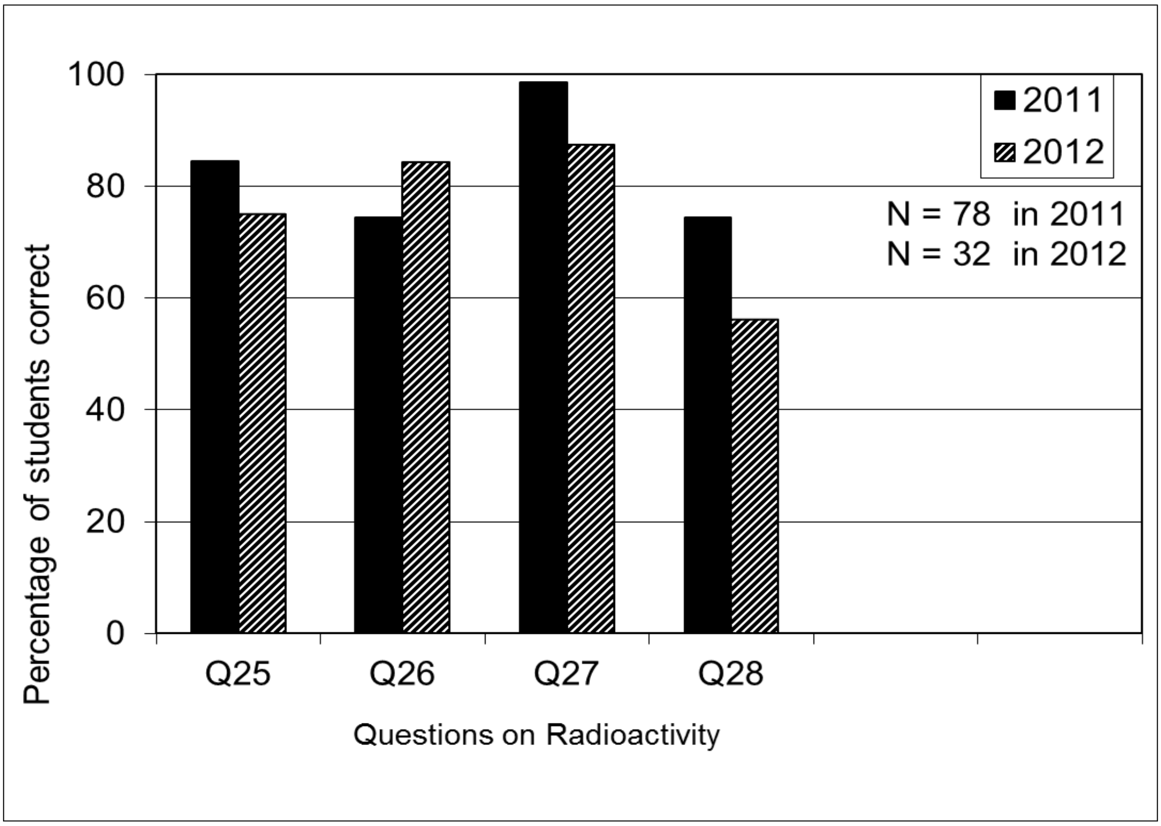

Figure 1: The results for a subset of questions in the final exam in 2011 and 2012.

The impact of their active learning may be further illustrated by the distribution of the exam results from Flinders for the subset of exam questions directly related to the material covered in the IB laboratory before the introduction of the new laboratories (2011) and after (2012) (Figure 1). In 2011, all the laboratories including the radioactivity laboratory were recipe based and in 2012 we have trialled one radioactivity IB laboratory. In 2011, the student number was high (N=78) because this topic was also delivered as a core topic for another degree and this requirement was changed in 2012 resulting in 32 students.

The results for the four radioactivity questions were aggregated and analysed by paired samples t-test. There was no significant difference between the two cohorts (p=0.317). Question 26 was analysed independently because it is related to the calculation of the half-life of a radioactive isotope which students in both years did in their laboratories. While there appears to be 10% increase in 2012, this was not significant by chi-squared analysis (p=0.255). Other studies have reported an improvement in conceptual understanding (Luckie, Maleszewski, Loznak, & Krha, 2004; Sundberg & Moncada, 1994; Udovic,Morris, Dickman, Postlethwaite, & Wetherwax, 2002) with inquiry-based adaptations but our results show no change.

Flinders differed from Curtin in that the IB laboratory was in between recipe based laboratories. This provided an opportunity to see if the inquiry experience improved student performance on subsequent recipe based laboratories. The IB laboratory was not included in this analysis as it had a substantially different marking scheme; instead the laboratories immediately before and after were analysed to minimise the impact of time on the results.

The results in Figure 2 show that students performed significantly better ($p<0.05$ by independent samples t-test) after the IB compared to before. Laboratory 4 was judged by the teaching team to be considerably more difficult than laboratory 2 so the improvement was not due to ease. The same assessors marked both reports. Other factors such as building expertise with time across a semester may provide an explanation but it is possible that IB laboratories lead to students thinking more deeply about subsequent recipe based laboratories.

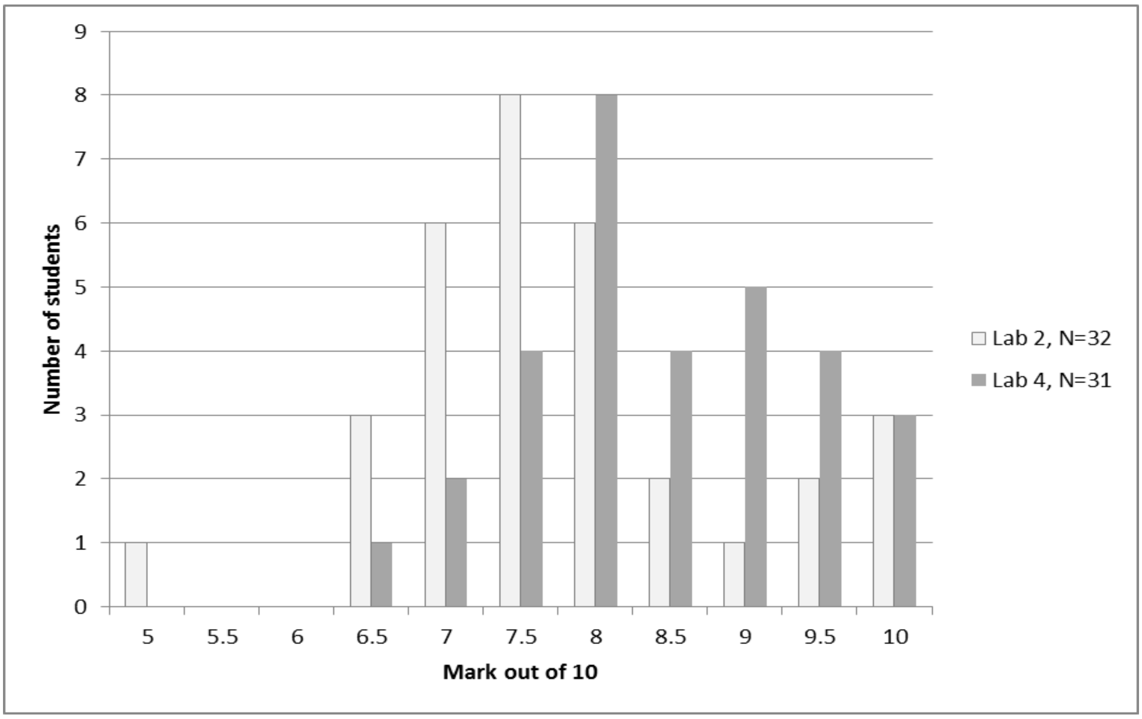

Figure 2: Recipe-based laboratory marks before (Lab 2) and after (lab 4) IB lab (lab 3).

Quantitative studies have also reported frustration from students engaged in inquiry activities (Sundberg & Moncada, 1994; Udovic, et al., 2002; Volkmann, Abell, & Zgagacz, 2005). In this regard, our study also supports these findings. For example, our evaluation of student attitude towards the IB practical in Table 1 also shows some disagreement from students for responses to the statements 2, 5, 6 and 7 in Table 1. Responses to statements 6 and 7 also show that some students do not like to come up with their own laboratory procedures. One of the factors contributing to this attitude is that students dislike the extra work required to think through problems on their own, reported in the studies by (Loughran & Derry, 1997). Another factor could the amount of time they need to spend in an IB laboratory. 50% of students agree that it takes a larger amount of time to complete the IB laboratory reports. See Table 1. Again this is in agreement with the findings of (Moss, 1997).

Analysis of messages on the discussion board on the online learning content management system (Flinders Learning Online – FLO) showed that a few students in this topic were not happy with the IB laboratory. Comments included:

> *"I'm actually having a lot of trouble regarding this lab... Do we really have to make our own from scratch, or can we do a simple experiment that has been done before regarding radiation? Because nothing is coming to my head when I am thinking of my own to do"*

The focus group of students responded to these messages from their fellow students. An interesting observation was that the dynamics of students leading students. Students in the focus group provided advice and support for those struggling with designing their laboratory. For example, they posted on FLO their experiences from the practice laboratory and their joy in designing very simple experiments to investigate the radioactivity of the items listed on the laboratory manual.

The focus group also provided an overview of the procedure and ideas "To be best prepared for this laboratory, we would highly recommend looking at (and answering) the questions you will find in the "Hints for your IB Lab" that you will find as a word document listed under week 5 on FLO. Useful resources will be the textbook, the radioactivity section in the "Lectures notes" listed under week 1 on FLO and the internet. It will also be a good idea to have your aims (what are you trying to investigate) and methods (what are you doing to collect data) written down in draft form before the laboratory. We should also state that the 3 hours allocated for the laboratory should be more than enough time (including to write up your aims, methods, results and conclusions in your prac manual) even if you are not 100% sure before you enter the lab (but as I say, answering the questions in the hints document will give you a better chance of being prepared). I hope this overview has been helpful and I hope you all enjoy the laboratory as much as we did. I am sure you will see some surprising results too"

Students in the focus group have taken videos of this particular laboratory on their own because they really enjoyed the experience. Student comments about the IB laboratories on topic evaluation at Flinders were positive. For example:

> *"Practicals helped me to understand what was expected of me to know" "I have done a Physics class before in first year, but most things I learned in this class were quite new to me and it gave me a really good refresher on Physics*".

In general, the survey results for both universities indicate positive responses. However, there are some variations in students' responses between the two cohorts which require further investigation. The literature (Thijs & Bosch 1995) indicates that some groups of students may benefit more from the inquiry method than others. In future at Flinders, we will offer the IB laboratory last in the practical sequence in order to give students reasonable time to become familiar with writing laboratory reports and to hone their laboratory skills. We will also reframe the laboratory manual to accommodate a guided-inquiry approach, in line with the findings of Zwickl et al. (2003) that first year students, as novices, may need some guidance. We will also give students more background material (with a Q & A section) to help them prepare for the activity. At Curtin, the students were required to complete 4 out of 5 experiments. Since the IB radioactivity laboratory was the fifth experiment, many students had completed the mandatory requirement so participation was low (N=32 students). In future radioactivity will be the fourth laboratory so we expect to collect better statistics.

Another interesting investigation would be to compare the responses of these non-physics majors students, with those majoring in physics, to investigate the possible role of intrinsic versus extrinsic motivation on student attitudes and behaviour.

Conclusions

While students at both universities are unfamiliar and feel uncomfortable with IB laboratories, they report that they have learnt more doing such laboratories, as compared to more traditional recipe-base laboratories, have had to think more about how to carry out the laboratory and, interestingly, had more fun doing the laboratories. Our study across two universities showed that while students have mixed views on IB laboratories, such approaches stimulate learning more than recipe based laboratories. We also found that student performance on associated assessment tasks indicates that inquiry based laboratories at worst do not negatively impact on student grades and may improve assessment outcomes.

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References

Abraham, M. R. (2011). What can be learned from laboratory activities? Revisiting 32 years of research. *Journal of Chemical Education, 88,* 1020-1025.

Bell, P., & Linn, M. (2000). Scientific arguments as learning artifacts: Designing for learning from the Web with K.IE. *International Journal of Science Education, 22,* 797–817

Boyer Commission on Educating Undergraduates in the Research University (1998): Reinventing undergraduate education: a blueprint for America’s research universities. Stony Brook: State University of New York at Stony Brook. Retrieved May 11, 2009, from www.naples.cc.sunysb.edu/Pres/boyer.nsf/.

Brickaman, P., Goramally, C., Armstrong, N., & Hallar, B. (2009). Effects of inquiry-based learning on students’ science literacy skills and confidence. *International Journal for the Scholarship of Teaching and Learning, 3*(2), Retrieved January 7, 2009, from http://academics.georgiasouthern.edu/ijsotl/v3n2.html

Gallagher, S. A., Stepien, W. J., Sher, B. J., & Workman, D. (1995). Implementing problem based learning in science classrooms. *School Science and Mathematics, 95*(3), 136–146.

Chatterjee, S., Williamson, V.M., McCann, K., & Peck, L. (2009). Attitude and perception of students toward guided and open inquiry laboratories. *Journal of Chemical Education, 86* (12), 1427.

Domin, D. S. (1999). A Review of Laboratory Instruction Styles. Journal *of Chemical Education 76*(4), 543.

Etkina, E., Karelina, A., Ruibal-Villasenor, M., Rosengrant, D., Jordan, R., & Hmelo-Silver, C.E. (2010). Design and reflection help students develop scientific abilities: Learning in introductory physics laboratories. *The Journal of the Learning Sciences, 19*(1), 54-98.

Etkina, E. & Van Heuvelen, A. (2007). Investigative science learning environment - A science process approach to learning physics.In E. F. Redish and P. Cooney, (Eds.), *Research Based Reform of University Physics, (AAPT)*. Retrieved August 25, 2013, from http://www.compadre.org/Repository/document/ServeFile.cfm?ID=4988&DocID=239

Etkina, E., Van Heuvelen, A., Brookes, D. T., & Mills, D. (2002). Role of experiments in physics instruction – A process approach. *The Physics Teacher, 40,* 351–355.

Healey, M. (2005). Linking research and teaching exploring disciplinary spaces and the role of inquiry-based learning. In: Barnett, R. (Ed.) *Reshaping the university: new relationships between research, scholarship and teaching.* (pp. 30-42), Maidenhead: McGraw-Hill/Open University Press.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88(1),* 28-54.

Horowitz, G. (2003). A discovery approach to three organic laboratory techniques: extraction, recrystallization, and distillation. *Journal of Chemical Education, 80*, 1039–1041.

Jones, S., &Yates, B. (2011). Learning and teaching academic standards project learning and teaching academic standards statement for science. Australian Learning and Teaching Council. Retrieved June 26, 2012, from www.olt.gov.au/system/.../altc_standards_SCIENCE_240811_v3.pdf

Kirkup, L. (2013). Inquiry-oriented learning in science: Transforming practice through forging new partnerships and perspectives. Australian Government Office for Learning and Teaching. Retrieved June 25, 2013, from http://www.olt.gov.au/resources?text=kirkup.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-Based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75-86.

Kolodner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education, 39*(3), 9-40.

Loughran, J., & Derry, N. (1997). Researching teaching for understanding: the students'perspective. *International Journal of Science Education, 19*(8), 925-938.

Luckie, D. B., Maleszewski, J. J., Loznak, S. D., & Krha, M. (2004). Infusion of collaborative inquiry throughout a biology curriculum increases student learning: a four-year study of "Teams and Streams". *Advances in Physiolog Education*, *28*(4), 199-209.

Laws, P. W., Rosborough, P. J. & Poodry, F. J. (1999). Women's response to an activity-based introductory physics program. In J. Gainen and E. W. Willemsen *Fostering Student Success in Quantitative Gateway Courses*, (Eds.) (77-87). San Francisco, CA: Jossey-Bass Inc.

Marshall, J.A., & Dorward, J.T (1997). Revisiting inquiry and prescriptive laboratory experiences in introductory physics. *American Journal of Physics, 65*, 418-428

Marshall, J.A., & Dorward, J.T. (2000). Inquiry experiences as a lecture supplement for preservice elementary teachers and general education students *American Journal of Physics 68, Physics Education Research Supplement*, 68 (7), S27-S36.

Moss, R. (1997). A discovery lab for studying gene regulation. *American Biology Teacher, 59*(8), 522-526.

Newton, T. A., Tracy, H. J., &Prudente, C. A. (2006). Research-based laboratory course in organic chemistry. *Journal of Chemical Education, 83,* 1844-1849.

Stewart, M. (2012). Understanding learning: theories and critique. In L. Hunt and D. Chalmers (eds) *University Teaching in Focus: A learning-centred approach*. Acer Press, Melbourne, 3-20

Sundberg, M. D., & Moncada, G. J. (1994). Creating effective investigative laboratories for undergraduates. *Bioscience, 44*(10), 698-704.

Thijs, G. D., & Bosch, G.M. (1995). Cognitive effects of science experiments focusing on students' preconceptions of force: a comparison of demonstrations and small-group practicals, *International Journal of Science Education, 17* (3), 311-323

Tobin K.G., (1990). Research on science laboratory activities: In pursuit of better questions and answers to improve learning. *School Science and Mathematics, 90*(5), 403-418.

Udovic, D., Morris, D., Dickman, A., Postlethwait, J., & Wetherwax, P. (2002). Workshop biology: Demonstrating the effectiveness of active learning in an introductory biology course. *Bioscience, 52(3*), 272-281.

Volkmann, M. J., Abell, S. K., & Zgagacz, M. (2005). The challenges of teaching physics to preservice elementary teachers Orientations of the professor, teaching assistant, and students. *Science Education, 89*(5), 847-869.

Weaver, G. C., Russell, C. B., & Wink, D. J. (2008). Inquiry-based and research-based laboratory pedagogies in undergraduate science. *Nature Chemical Biology, 4(*10), 577-580.

Willison & O'Reagan (2007). Research Skill Development Framework Retrieved 9 April, 2010, http://www.adelaide.edu.au/clpd/rsd/

Zwickl, M. B, Finkelstein, N & Lewandowski, H. J. (2013), *A framework for incorporating model-based inquiry into physics laboratory courses" arXiv:1301.4414v1 [physics.ed-ph]*. Retrieved January 18, 2013, from http://www.colorado.edu/physics/EducationIssues/zwickl/Resources/Zwickl_framework_for_model-based_inquiry.pdf.