Evaluation of Group Based Inquiry Oriented Learning in Undergraduate Chemistry Practicals

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Abstract

This work examines and evaluates the implementation of inquiry oriented learning (IOL), as an alternative to the traditional 'recipe-style' expository laboratory teaching method, with the aim of enhancing students' experience and engagement in chemistry laboratory practicals. Small groups of students in the first year of their undergraduate degree were assigned a practical problem and were required to devise an appropriate experimental protocol that would allow them to successfully execute the assigned task. With a response rate of 64% (47/73), over 80% of respondents agreed that IOL based practicals were interesting/enjoyable and created awareness about the challenges that researchers in chemistry experience. Only 50% of the respondents agreed that they felt confident initially with the open-ended nature of IOL activities; 45% felt that more appropriate background information on the practical should have been provided. However, the level of guidance provided by the demonstrators was considered appropriate (70% agreement). While 70% agreed that IOL activities enhanced their skills in investigative/critical thinking, use of laboratory equipment and team work, only 55% agreed that their observation/recording and data analysis skills were developed and that increased understanding of the course content was achieved. Whilst the implementation and evaluation of IOL in chemistry practicals is ongoing, there is no doubt that students perceive that they learned or practised a range of graduate attributes (such as teamwork, research, problem solving etc.) while engaging in a group based IOL activity.

Introduction and Background

It is a well-documented and understood view of most chemical educationalists that good quality laboratory practical work has the potential to engage students, helping them to develop a set of basic skills and enhance their understanding both of the process of scientific investigation and of chemistry concepts. Furthermore, a sound understanding of the role chemistry practicals play in the overall learning experiences at first year undergraduate level, would allow staff to utilise such experiences in future years as students continue through their undergraduate degree programs. Practicals aim to teach students how to conduct laboratory experiments with a focus on the cognitive skills for recording and observation, including how to write a report using the data acquired (Hopper 2014). A further consequence of experiencing practical work, particularly in chemistry, is the acquisition of an understanding of hazard, risk and safe working practices. These are just some of the many different reasons for choosing to use a practical activity in a chemistry lesson.

When done well, practical work can stimulate and engage students' learning at different levels, challenging them mentally and physically in ways that other science experiences cannot (SCORE 2009; Woodley 2009). Whilst a good chemistry practical activity is one that is effective in communicating a clearly defined set of ideas, this can be difficult to achieve when the teachers' identified outcomes are different from the outcomes that students perceive. Thus it is crucial that with any practical activity, clear and concise instructions about the aim and learning objectives are communicated to increase the practical activity's effectiveness as a learning experience, for the students. If the goals and objectives are not expressed in terms of allowing students to critically evaluate and engage with the material while being able to apply scientific knowledge, understanding and skills, it could lead to students simply following 'recipes' during practical activities for the sake of completing a task.

Whilst many different approaches to laboratory based teaching exist, Domin (1999) characterizes four types: expository, inquiry, discovery and problem-based. These can be applied to the different laboratory teaching methods based on the expected outcome of the laboratory session, the student's approach and whether the procedure was supplied (Table 1). The outcome of any laboratory activity is either predetermined or undetermined. Expository and problem-based activities typically follow a deductive approach, while discovery and inquiry activities are inductive (Tsaparlis and Gorezi 2007). By far the most common amongst these is the expository or 'recipe-style' laboratory class, which is instructor-centred (McDonnell, O'Connor and Seery 2007; Tsaparlis and Gorezi 2007) and the student has only to follow the instructor's directions or the procedure (from a manual).

Table 1. **Descriptors of the laboratory based teaching styles (Adopted from Domin, 1999)**

Style	Descriptor		
	Outcome	***Approach***	***Procedure***
Expository	Predetermined	Deductive	Given
Inquiry	Undetermined	Inductive	Student Generated
Discovery	Predetermined	Inductive	Given
Problem-based	Predetermined	Deductive	Student Generated

Whilst the expository style of laboratory based instruction has been encompassed into most chemistry degree courses, there has been much discussion on the merits of such a model (McDonnell et al. 2007). Among the criticisms are the claims that the level of learning is limited, and that students are unclear about the aims of the practical and unsure of what the results mean or how they are applied to the theory provided in the lectures (McGarvey 2004). In addition, traditional style practicals often leave little room for creativity or contextualisation, and are often a verification of a known quantity or a testing of a theory that has been presented in lectures (McDonnell et al. 2007). This leaves no room for the students to develop skills relating to investigative and independent critical thinking capabilities which are crucial for any science graduates in their future scientific career.

Inquiry-Oriented Learning (IOL) is a student-centered, activity-intensive approach to learning. While many alternative versions have been described, including Inquiry Based Learning (IBL), Problem Based Learning (PBL), and Process Oriented Guided Inquiry Learning (POGIL) they are all variations on the theme of placing students at the core of their own learning, engaging and stimulating both learning outcomes and student confidence. The IOL approaches towards learning have been successfully implemented over the last 15 years as a compelling method of invigorating undergraduate science education both in Australia and internationally (Brew 2003; Creagh and Parlevliet 2014; Lee 2012; Rayner, Charlton-

Robb, Thompson and Hughes 2013). In science education, investigation and inquiry underpin academic scholarship through which a problem or question is typically approached by forming appropriate hypotheses, designing experiments to suitably test such hypotheses, and gathering, interpreting and communicating results in the context of the original problem. Other activities that are strongly aligned with such scientific practice are critical thinking, evaluation, extrapolation, and deductive and inductive reasoning. Therefore it is apparent that IOL approaches should not just be a part of, but rather the fundamental basis for science education, being initiated and scaffolded during the early parts of the educational journey, aiming to develop independent, critical thinking science practitioners at the end of a tertiary qualification (Rayner et al. 2013).

Previous studies, often in single subject or discipline areas, have validated the benefits of IOL in undergraduate science courses through observation and examination of data, as well as qualitative and quantitative feedback from students and employers (Brew 2003; Creagh and Parlevliet 2014; Lee 2012). Recent research towards the development, implementation and evaluation of IOL practicals through interdisciplinary collaboration in first year biology, chemistry and physics laboratory teaching programs, has been shown to enhance the overall skills that would otherwise provide students with isolated or disjointed forms of experiences that they may attain in a single subject or discipline (Rayner et al. 2013).

Undergraduate students who take chemistry courses at the university in this study rarely perform any type of laboratory work other than expository, except for research in their final year capstone projects. Thus IOL based practical activities allow us to rectify many issues that have been apparent due to the use of the more traditional recipe style approaches. In implementing the IOL activities, students take responsibility for devising the experimental procedure, allowing them to reflect on whether a particular experimental procedure is suitable, why and what information is provided by the outcome of the experiment (McDonnell et al. 2007). As a result students start to examine the value of an experiment and think about it in the context of a problem solving scenario. This contrasts significantly with recipe-style laboratories, where students can complete an experiment and produce a report without ever understanding or thinking about the experiment involved. Furthermore IOL based practical activities are more student-centred, contain less direction, and give the student greater responsibility, as well as ownership of the laboratory activity.

A key way to increase student engagement is to offer a diverse range of laboratory activities into laboratory teaching programs (Naiker, Wakeling and Aldred 2013). Furthermore, it has also been reported that effective small group collaborative learning where students worked in a self-directed environment in view of fostering interdependency, encouraged teamwork, communication skills and negotiation between group members (Lawrie, Gahan, Matthews, Weaver, Bailey, Adams, Kavanagh, Long and Taylor 2014). To improve the quality of chemistry education at our institution, over the last two years (2013 – 2014) we have investigated the implementation of IOL based practical activities in a first year introductory chemistry course (SCCHE1012). Students completed one of their laboratory practicals in groups of 5–6 over a period of six weeks, with each group completing an individual task, acivitity and topic. Students were assigned contextualised problems that required the application of theoretical chemistry and practical concepts they had acquired previously in lectures and/or other expository laboratory practicals. The implementation of the IOL based practicals was conducted concurrently with 'traditional' laboratory sessions.

It has been recognised that the implementation of laboratory practicals where the student generates the procedure for the practical presents a number of significant challenges (Edelson 1999; McDonnell et al. 2007; Tsaparlis and Gorezi 2007). In this paper, the operation of these IOL based practicals alongside the traditional laboratory practicals is described and the additional benefits that result from combining this new approach with the existing system are examined. This method requires more laboratory time than would normally be assigned to a pre-determined practical, but we believe the benefits observed make the time investment worthwhile.

Methodology

The IOL practicals were implemented in place of traditional laboratory practicals for a chemistry course taken by a cohort of first year students enrolled in a range of programs (such as Biomedical Science, Food and Nutritional Science, Bachelor of Science, Geology and Education) in which chemistry is a core or an elective course.

Students were randomly divided into small groups of 5-6 and each group was assigned a team leader. Each group was allocated a practical project (Table 2) with each practical activity selected to be at an appropriate level, with most of the required theory having being previously covered in lectures or readily accessible to the students. Additionally, during their traditional style laboratory sessions students had exposure to the practical skills required to successfully execute each IOL problem. For example if a topic required the skills of titration, these students would have already covered that in their practicals earlier in the semester or in that academic year.

Table 2. Examples of IOL practicals and their relationship to the content covered in SCCHE1012

Project Title	Topics Covered
Determination of benzoic acid in commercially available soft drinks	Spectroscopy (UV-Vis), Beer-Lambert Law, calibration and extrapolation
Determination of caffeine in coffee sold in various outlets on Campus	Spectroscopy (UV-Vis), Beer-Lambert Law, calibration and extrapolation
Determination of the precent (%) of cranberry juice is in a mixture of cranberry-apple juice available commercially (Edionwe, Villarreal and Smith, 2011)	Spectroscopy (UV-Vis), Beer-Lambert Law, calibration and extrapolation
Determine Vitamin C in lemon and orange and compare	Sample preparation, iodometric titration, stoichiometry
Determine the % of copper in a given crude sample	Titration, stoichiometry
Determination of minerals in energy drinks that is commercially available	Spectroscopy (Flame Photometer), calibration and extrapolation
Determination of minerals in fruit juices and beverages that is commercially available	Spectroscopy (Flame Photometer), calibration and extrapolation
Determination of total bitterness in popular Australian beers	Organic extraction, centrifugation, spectroscopy (UV-Vis)

Determination of water hardness and alkalinity from common local water sources	Titration, stoichiometry
Identify six organic compounds in unlabelled vials	Spectra (UV-Vis, IR and NMR) data interpretation, physical properties of organic compounds, functional group tests for organic compounds

Prior to week 6 of a typical 12 week semester, each group was provided with background material introducing IOL (Appendix 1) and in week 6 they were given a problem related to analytical or experimental chemistry that they had to thoroughly investigate through group discussions, literature review of topic and methodology, etc. The problems were analytical in nature and required each group to devise an appropriate plan so that they could successfully carry out the necessary analysis and experiments, with the aim being to report the findings or a solution for the given problem. At the end of the laboratory session in week 6 each group submitted a summary of their group discussions related to their problem, prior to further investigations (Appendix 2). The group also provided details of their workload distribution i.e. who was responsible for preparing background information and methodology investigations etc. Each group was required to liaise with the lecturer by week 9 to discuss their respective proposal and plan to attempt to solve the problem. Once the lecturer approved their proposal, each group was required to make a list of all samples, reagents and other chemicals, materials and equipment that was required. This list was passed on to the laboratory technicians who assisted by having all requirements in place for each group to conduct their respective experimental procedure(s) in week 11. Figure 1 shows a schematic flowchart outlining the implementation of IOL projects and requirements from students at each stage. This required a tremendous amount of planning, patience and willingness from the teaching team, including technicians, because up to six different practicals were running at once, over two separate sessions.

The assessment weighting for the laboratory components of the chemistry course (SCCHE1012) was 25%, with 10% contributed by the IOL based practicals, whilst 15% were allocated for the traditional recipe style approach. The experimental plan submitted in week 9 of the project acccounted for 5% of the 10% mark allocated for the IOL practicals. For the experimental plan, students were expected to outline some of the initial experiments that they wished to conduct and to describe how they expected those experiments would help to solve their problem. Students were not expected to provide much detail at this stage of the project because they were used to the ‘recipe-style’ labs, and one of the overall aims of the project was to encourage reflection on the work completed at each stage, and subsequent modification of experimental procedures. On completion of the project each group was required to submit a written report (one for each group of 5 - 6) outlining their approach, findings, discussions, conclusions and recommendations, which contributed the final 5% to their overall assessment of this course.

Ethics approval (# B14-138) was obtained to evaluate the effectiveness of the IOL model implemented and the extent to which it improved student learning in first year chemistry (SCCHE1012) practicals. Hardcopies of a slightly modified survey questionnaire developed by Rayner et al., (2013) were used to gather feedback from students. Question 5 (The pre-lab quiz/questions prior to the practical were beneficial) in the original questionnaire was not included in the current modified version, since there were no pre-lab questions included when each group was assigned their IOL projects. The survey questionnaire consisted of a mixture of qualitative and quantitative responses and was completed by undergraduate students who were enrolled in the first year chemistry course during semester 2, 2014, during a routine tutorial session (in week 12). Participants were recruited through an advertisement that was posted on the Moodle course page for SCCHE1012, as well as being conveyed verbally in lectures, tutorials and practicals by the researchers involved in this project.

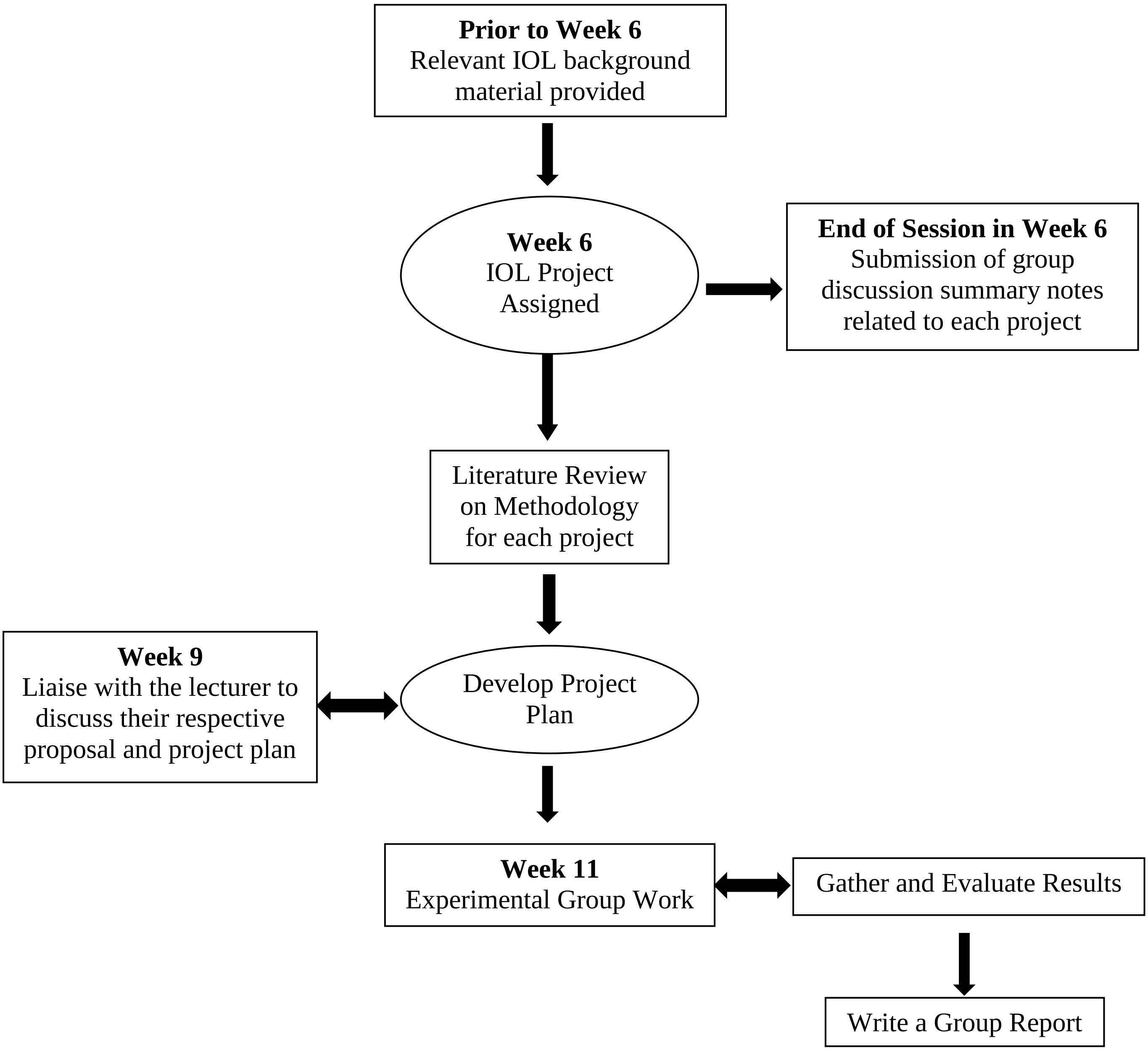

Figure 1. Schematic flowchart outlining the implementation of IOL projects and requirements from students at each stage

The data obtained from the survey included descriptive statistics and the grouping of the qualitative responses by theme. The quantitative data were analysed using a Likert-scale (5-1), with 5 being Strongly Agree (SA), 4 Agree (A), 3 Neutral (N), 2 Disagree (D) and 1 Strongly Disagree (SD).

Unstructured feedback was also sought from the demonstrators associated with the IOL practicals, as well as an independent peer (academic) feedback.

Results and Discussion

The survey was completed after the IOL practical reports had been submitted by 47 students (64% response rate), comprising 23 females, 15 males and 9 who did not specify their gender. This cohort of students had been exposed to expository style chemistry practicals in the initial introductory chemistry course SCHCHE1011 in Semester 1, 2014 as well as in SCCHE1012 in Semester 2 up to week 6 when the IOL based problems were assigned. Furthermore, the majority of this cohort of students was domestic Australian students (95%), predominantly from a regional and/or rural background.

Student Evaluation

Both quantitative and qualitative student feedback were categorised based on key themes such as the IOL practical:

- being interesting and enjoyable,
- being unique and helping with confidence building,
- requiring more guidance,
- developing understanding of the subject and
- developing skills

Students were also asked for suggested improvements and recommendations. The percentage of responses to Likert-style questions relating to these aspects of the IOL practical is summarized in Figure 2.

IOL Practical Being Interesting and Enjoyable

The students overwhelmingly agreed (85%) with the statement that they considered the IOL based practical to be interesting and enjoyable. Based on qualitative responses, the main reasons for this were: because it was fun; they were allowed to work as a team; it was beneficial due to its problem solving nature which allowed for formulating and devising of one's own self-directed (independent) approach towards completing the tasks.

IOL Practical Being Unique and Confidence Building

As expected, over 65% of the students agreed that they found IOL practicals to be very different in nature to non-IOL practicals which they had previously encountered in the SCCHE1012 course. Only 50% of the students agreed that they felt confident with the open-ended nature of the IOL practicals, with close to 40% being neutral or unsure about their confidence in undertaking practical tasks using this approach.

The lack of confidence, or insecurity, relating to undertaking an activity which is different to their previous experiences is expected with first year undergraduate students who lack exposure to independent learning at this stage of their tertiary experience. This was evident from the qualitative feedback such as: *"although I felt flustered at the start I was able to gain a sense of what I could be doing in the future"*, *"I was worried I'd make mistakes"* and *"(it was) challenging not being able to refer back to previous pracs or reading as it was all new"*.

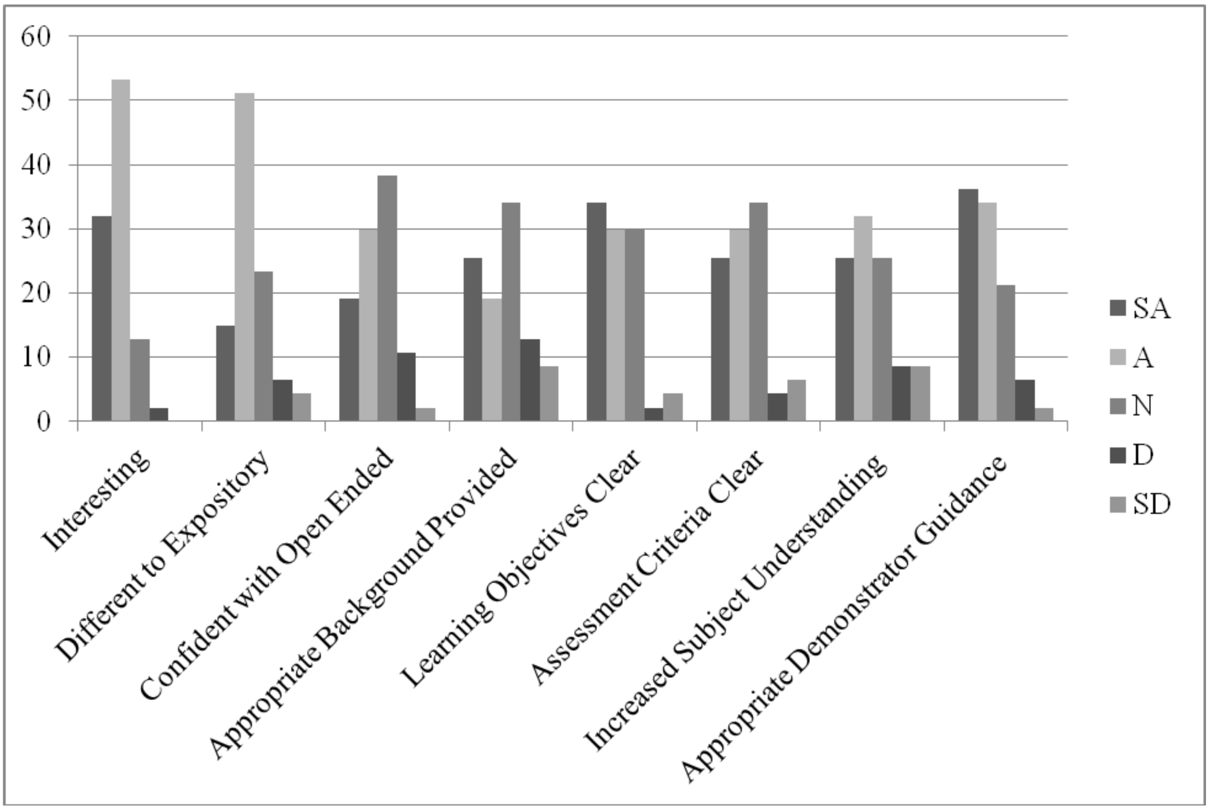

Figure 2. **Response (%, vertical axis) of students to quantitative questions pertaining to several aspects of the IOL practical tasks**

Guidance for the IOL Practical

Whilst >60% of students agreed that the learning objectives for the IOL practical were clearly outlined and 55% agreed (30% neutral) that the assessment criteria were clearly outlined, only 45% agreed that appropriate background information (in relation to the assigned problem) was provided for these practicals. The last point can be explained based on the fact that the IOL practical was deliberately designed to be investigative in nature, so apart from providing the various problems to each group they were directed or instructed to undertake appropriate literature searches to gather the required information to devise their own experimental protocols. The students had been exposed to similar protocols in some of expository practicals they encountered in their first semester chemistry courses. Despite the perceived lack of background information provided to each group, 70% of students agreed that the level of guidance and assistance offered by the demonstrator(s) during the IOL practical sessions was appropriate. This highlights the crucial role support staff play in making sure that an innovative style of laboratory teaching achieves its aims and objectives.

Understanding of Subject

More than half of the students (58%) that responded claimed that completing an IOL practical had increased their understanding of the theoretical concepts taught in lectures and tutorials pertaining to the individual problems attempted. This observation suggests that students enjoyed correlating their course content to the requirements needed to complete the given task, as was evident from the qualitative feedback such as: *"the prac and results consolidated this semesters content for me"; "Using lecture material in a real world way"; "Better understanding of pracs and theory behind them";* and *"Applying previous knowledge to new situations"*

Being an Experimental Researcher

Exposure to IOL practicals allowed students to gain experience of being involved in research based activities, with 83% agreeing that they felt that the IOL practical assisted them in understanding the challenges that experimental researchers in the field of science and specifically chemistry face. This is consistent with similar findings in research done elsewhere (Berenguer-Murcia, Bueno-Lopez and Lozano-Castello 2012). The fact that students at this early stage of their program have some degree of realisation about the connection between a problem and its implications in the 'real world' suggests that they are thinking about their future careers and the broader role of science. This was highlighted in qualitative responses to a question asking about the main lesson learnt from this practical, which included feedback such as: *"don't just research to get the marks, research to understand"; "Importance of research and planning prior to entering the lab; "Ability to research a problem and discover a solution"; "Greater knowledge of substances from research"; "Experience of what it is like as a "proper" research scientist"; "How a scientist works"* and *"Develop skills to solve problems".*

Skills Related to IOL Tasks

The responses (%) to quantitative questions relating to how various skills were impacted by completion of the IOL practical are illustrated in Figure 3. Up to 70% of the respondents agreed that completing an IOL practical had enhanced their critical thinking and self-guided investigative skills to a greater extent than non-IOL practical activities encountered in SCHE1012. This was further highlighted in qualitative responses to a question relating to the main lessons learnt from this practical which included feedback such as: "*Thinking in different way about practicals and teamwork"; "To think for ourselves/critical thinking"; "Learn to do prac by yourself (somewhat independent)";* and *"Feel what it is like to do something without the teacher 'holding our hand'".*

Interestingly only 53% of students agreed that the IOL practical assisted them with developing observation skills, while only 56% agreed their recording and data analysis skills were assisted, with close to 40% being neutral or not sure as far as these two skills sets were concerned. Observation, recording and data analysis skills are crucial for scientists because they enhance their ability to understand and interpret outcomes relating to a problem. It is anticipated that as these students progress through their individual undergraduate programs and systematically gain exposure to scientific problem solving, these important skills sets will expand.

Over 70 % of the students agreed that completing an IOL practical assisted them in developing skills around the use of laboratory equipment, and skills necessary to work effectively in a team environment. Both of these skills are vital to conduct research in science related disciplines. These perceptions were further highlighted in qualitative responses regarding skills development in these areas, which included feedback such as: *"Design a prac and use equipment"; "Using (playing) new equipment"; "Collating and discussing results in group";* and *"I would much rather work in a group due to the debates on the method within the group furthered my understanding".*

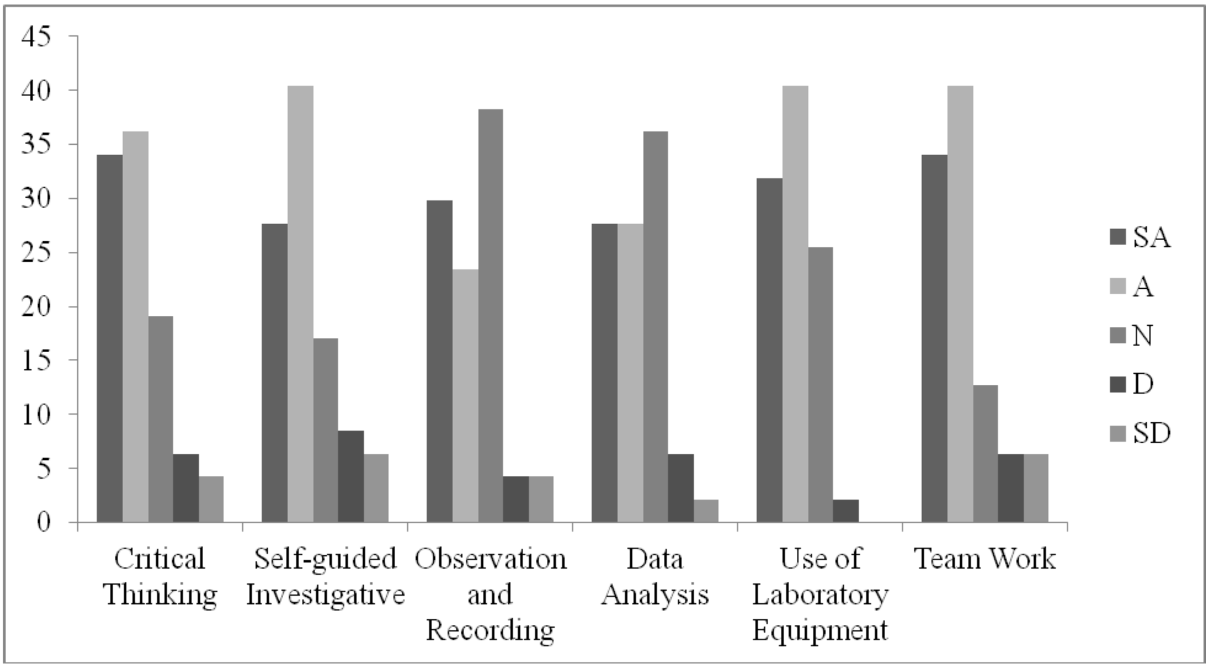

Figure 3. **Response (%, vertical axis) to quantitative questions pertaining to how skills were impacted by completion of the IOL related practical tasks**

Suggested Improvements and Changes

Responses to the qualitative questions relating to aspects of the IOL practical that needed improvement indicated that the majority of the students felt that due to the open-ended nature of the IOL practicals, more guidance and assistance towards understanding the specific problems assigned would be beneficial. Student also stated that rather than them being assigned a specific problem, they should be given an option of choosing their preferred problem from a range of provided topics.

Whilst 74% of the students felt that the IOL practical helped to develop team work skills, a number of students commented on issues relating to working as a team and group dynamics, which negatively impacted on their experience: *"I felt I did everything and my group did nothing"; "An opportunity to work independently would eliminate potential for group dynamics/effort to influence individual results"; "(it was) quite difficult to gain a good understanding when trying to do a pretty rushed write-up and deal with a team that gave very little participation*"; *"Hard to get in contact with other group members"; "Group members don't contribute equally"; "Get a good group of people who are organised"; "Don't work in teams"* and *"Group work is terrible".*

Students suggested that a smaller group size (2 - 4 people) would be better suited to the IOL practicals than the current randomly selected 5 - 6 people, as this would improve group organisation, management and communication amongst the members. They felt larger group sizes leads to difficulties in contacting members and organising meetings with all group members, which culminates in only a few contributing to the many different aspects required to efficiently complete the IOL practical. Such issues in group dynamics may not only impact on student learning, but affect individual assessment in terms of what grades they attain prompting suggestions to assess the IOL task based on individual performance and contribution through peer assessment.

It was suggested that the IOL practical should be completed over two practical sessions in order to allow for verification and consolidation of data in the subsequent week should the group confront difficulties in the first instance. Furthermore, students felt they need to be provided with more time for data analysis and preparation of the final report, and the current one week submission time is not sufficient. This would also allow additional discussion time for the group post-practical.

Demonstrator and Peer Review Comments

Apart from evaluating students' experiences, written feedback was sought from demonstrators and a peer (colleague within our School) who were invited to come and observe a few of the IOL practical sessions. A representative selection of comments from a demonstrator and peer reviewer are reproduced below.

Postgraduate Demonstrator Comments

> *"IOL is a good opportunity for the students to think and work more independently. However, such an approach can be time intensive and a bit daunting for them at least in the beginning."*
>
> *"This type of learning may bring out the capabilities of students which otherwise have not been invigorated as yet!"*
>
> *"IOL practicals allow students to have more interactions and discussions with fellow students than the expository practicals give them and a feel for working in a team/group."*
>
> *"My experience with this problem based practical demonstration was positive. I was surprised with the diversity of ideas that students were coming up on the given problems, though some are not technically feasible in the laboratory."*
>
> *"I felt like students had a lively discussion on ideas within the group and some students were eager and ready to take responsibilities/ leadership more happily."*
>
> *"When it comes to actually conducting the experiments, most groups had a clear idea of what they were doing as they had already got approval of the methodology from the course co- coordinator. However, some students felt frustrated when the test results didn't work well which suggests they seriously had a good go at completing the tasks successfully."*
>
> *"I personally recommend that this type of study can build the confidence and intellectual level in the students. It will at least give a basic idea about research study and team effort."*
>
> *"Unfortunately, in some cases we could not see an equal effort/ contributions from all the students in the group."*

Peer Review Comments

> *"For most students the experience seemed to be worthwhile with them having planned and executed their own experiment to answer a question while negotiating a group situation. They seemed engaged and certainly were enhancing their skills in the laboratory. The lecturer and demonstrators seemed to have a good rapport with the students and helped navigate them through the decision making process as necessary. The students showed a good level of respect for the teaching team and were happy to seek their advice, help and ideas. The teaching team, including the laboratory technicians, should be congratulated for attempting and succeeding in introducing a*

> *new learning style into the course. With a degree of refinement I believe this should become an integral aspect of the SCCHE1012 course going forward."*

Both the demonstrator and peer reviewer feedback mostly reinforces the suggestions and comments that were highlighted by the students' evaluations. In accordance with findings from previous work (McGarvey 2004), the main negative aspect highlighted by the demonstrator feedback is that this style of practical work is certainly more demanding on both students and staff in the laboratory. More laboratory time than that required for an expository practical is required and also the teaching staff needs to be very familiar with the material at a theoretical and practical level, and they must proactively engage with the students to facilitate their learning.

Recommendations and Implications

Whilst the implementation of an IOL activity in our first-year, second semester chemistry course over the last two years was generally a success, we believe that this can be further improved by incorporating the following suggestions in future years:

- Increasing the number of demonstrators (from the current 3 to 4 or 5) during the IOL practical sessions will alleviate the workload on the teaching staff and allow more interaction and engagement with students. Furthermore, the personalities of the demonstrators are very important because they are required to be able to work independently and be proactive in helping students, yet willing to seek advice from the lecturer as necessary. More preparation for the demonstrators via workshops about IOL learning and the types of specific problems being investigated is also important. However, as suggested by McGarvey (2004), with more experience in the supervision and management of IOL practical work, the teaching staff will acquire a better understanding of what to expect from students according to their level and experience and they will learn to focus on student learning during practicals sessions.
- To avoid some of the issues pertaining to group dynamics, more effort needs to be placed on group selection. Group size should be reduced to no more than four with a gender and age mix. It is also recommended that if a group is not functioning well the lecturer should intervene at the earliest possible time and perhaps consider meeting with the entire group to discuss the issue.

Conclusions

Inquiry Oriented Learning based practicals have been used successfully as an alternative laboratory learning experience within a first year chemistry course over the last two years. The implementation of this alternative laboratory teaching style complements the existing expository approach and provides students with stimulating problems to tackle in small groups. Increased class participation and engagement were observed as a result of this change in approach. This observation was confirmed by feedback obtained via student evaluations and demonstrator and peer reviewer comments. Whilst the implementation of IOL in chemistry practicals is ongoing, there is no doubt that students perceive that they learned and practised a range of graduate attributes (such as teamwork, research, problem solving, etc.) while engaging in the group based IOL activity.

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Appendix 1

PRACTICAL 3 & 5 (Weeks 6 and 11)
INQUIRY-ORIENTED LEARNING (IOL)

AIM

To apply student centered instructional techniques such as inquiry-oriented learning (IOL) to effectively achieve valid learning goals whilst resolving problems that are related to analytical/experimental chemistry.

INTRODUCTION

Learning is perceived to be at the highest and efficient when we are at the centre of our own learning. Inquiry-oriented learning (IOL), also known as inquiry based learning (IBL) is a learning process through questions generated from the interests, curiosities, and perspectives/experiences of the learner(1). When investigations commence from our own questions, curiosities and experiences; learning can become a motivating process that can add more fun to solving a given problem. IOL requires necessary approaches to learning that is based on a process of inquiry/enquiry, study and exploration, in which the student takes considerable responsibility for their own learning. The following outlines the core concepts of IOL(2):

- **Effective learning occurs when students' learning experiences are engaging**, that is, when students are doing rather than just listening.
- **In inquiry-oriented learning, students take on more responsibility** for identifying precisely what they need to learn and finding resources which will allow them to fill their knowledge gaps.
- **Inquiry-oriented learning can begin in first year** and progressively help students to develop their research skills as self-directed learners.
- **Students learn to identify and find answers** to the questions that they need to ask and the resources that they need to draw upon in solving any given complex (often real world problems).

The following trajectory best depicts the general theory that expands the inquiry based learning model(1):

The aim of utilising the IOL model in this practical exercise is to increase student engagement with the view of enhancing the quality of learning and reduce challenges in the learning environment. When the context of learning is both relevant and requiring active engagement, student learning is expected to be maximised.

The following are some useful sites that are recommended to increase your understanding of the IOL concept:

- https://www.google.com.au/search?q=inquiry+based+learning&tbm=isch&tbo=u&source=univ&sa=X&ei=v1kVUvrLIIOplQXIo4HQAw&sqi=2&ved=0CGYQsAQ&biw=1680&bih=879
- http://www.pogil.org/about
- http://www.teachinquiry.com/index/Introduction.html

REFERENCES

(1) http://www.inquirylearn.com/Inquirydef.htm
(2) http://sydney.edu.au/business/learning/staff/teaching/enquiry-based_learning

PROBLEM AND WORK PLAN

- In **week 6** each group will be a given a problem related to analytical/experimental chemistry which they will have to thoroughly investigate through group discussions, literature search etc.
- The problem will be of analytical in nature and will require each group to devise an appropriate plan so that they can successfully carry out the necessary analysis/experiments in view of reporting the findings to the solution for the given problem.
- Each group will be required to liaise with the Course Coordinator by **week 9** to discuss their respective proposal/plan that they have in place to attempt the problem.
- Once the Course Coordinator approves your proposal, each group will be required to make a list of all samples, reagents/chemicals, material and equipment that is required within **week 9**. This list will be passed on to the technicians.

- Each group will carry out their respective experimental procedure(s) in **week 11**.

INSTRUCTIONS FOR WRITING YOUR REPORT

- In **week 9** you will be required to submit a group proposal outlining how your group plans to solve the given problem. Outline the questions and hypothesis your group has formulated relating to the given problem.
- After completing your experiments in **week 11**, you will be required to submit a final group report outlining the following: Title, Authors (group members), Introduction, Hypothesis, Experimental Procedure, Results (tables, graphs etc.), Discussion, Conclusions and References.
- You are to submit the written report within 7 days of completing your practical activity in **week 11**.

INSTRUCTIONS FOR SUBMISSION

You can submit your group report by placing it in the assignment box with the course coordinators name on it inside the Y building (Level 1) or by handing it to the course coordinator (Office Y137).

Appendix 2

PRACTICAL 3&5 (Weeks 6 and 11)
INQUIRY ORIENTED LEARNING (IOL)

Find out the **% of copper** in a given crude sample

GROUP DETAILS

1. ___________________________ (Team Leader)
2. ___________________________
3. ___________________________
4. ___________________________
5. ___________________________
6. ___________________________

NOTES (To be submitted at the end of practical session in week 6)