Guided Inquiry Learning in an Introductory Chemistry Course

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Abstract

Foundations of Chemistry (FoC), the University of Adelaide's introductory chemistry pathway, recently underwent a complete restructure to assume no prior chemistry knowledge in order to better cater to students with little or no chemistry background. The restructure introduced Process-Oriented Guided Inquiry Learning (POGIL) style activities in lectures to deliver the majority of the course content and a new online learning platform for summative assessment. Three entirely new FoC courses were developed, one in each of semester 1 (FoC IA), semester 2 (FoC IB) and the University's Summer Semester (FoC IS). Successful completion of all three courses provides students with a pathway into second year Chemistry in addition to the pathway provided by completing Chemistry IA and IB. To date, FoC IS has run from 2013 to 2015, with half of the students in each of these classes progressing to level II Chemistry courses. This paper outlines the restructure process that led to the creation of three new courses and how these developments have impacted student learning outcomes. Students have responded positively to the restructured courses, and end-of-semester results for FoC IA and IB have seen an increase in the proportion of Distinction and High Distinction grades.

Introduction

Since 2003, students enrolling in level I Chemistry at the University of Adelaide have been streamed into either Chemistry I or Foundations of Chemistry (FoC) based upon their chemistry background (the former has a specified grade achievement for Year 12 Chemistry as a pre-requisite). This distinction has proved critical and over this time we have found that students are more able to appreciate, and pass, a chemistry course that is matched to their background, resulting in vastly improved educational outcomes. First year chemistry is available as an elective for all students enrolled in the University's Bachelor of Science degree, and is a core component of a number of other degree programs, including Bachelor of Animal Science, Bachelor of Health Sciences, Bachelor of Viticulture and Oenology and multiple engineering degrees.

During 2008–2009, the Chemistry discipline revised the Chemistry I curriculum to better match the South Australian Certificate of Education (SACE) Year 12 Chemistry syllabus, and in 2010 the discipline began to closely look at our FoC courses, which were first developed in 2003. At that time, almost all the enrolling students had at least completed Year 11 Chemistry at secondary school. Prior to 2012, FoC IA (semester 1) and IB (semester 2) assumed knowledge of Year 12 Chemistry, but did not have this as a pre-requisite for enrolling in the courses. Over time, the class size has grown dramatically, mostly because more students are now coming in with no formal chemistry knowledge (i.e., having only Year 10 general science knowledge). FoC class sizes had been increasing steadily since 2009, but have risen substantially in recent years: from around 250–300 students in 2011, to 350–400 today. The

FoC IA class of 2015 has its highest enrolment to date of 433 students. Chemistry is often referred to as the “central science”, as it is a pre- or co-requisite for many non-Chemistry-focused degree programs (such as Health Sciences and Animal Science) in which students are enrolled. Many of these students who are required to do first year chemistry as part of their degree do not have a strong background in the subject.

Student-Focussed Teaching

A restructure of the FoC courses was deemed necessary as there was evidence that the course material prior to 2012 was being presented too rapidly for a large proportion of the students in the class (particularly those without any prior chemistry knowledge) to learn effectively. It was decided to revise the course content completely so that FoC IA assumed no prior chemistry knowledge. In addition, the laboratory experiments for FoC were previously not aligned with the material presented in lectures, which did not provide an optimum learning experience for students. A working group, comprising the authors of this paper, was convened to explore a variety of student-focussed, small group-based teaching methods. A number of such methods exist and their value is well-documented in the educational literature (for examples, see Boud, Cohen and Sampson 1999; Bowen 2000; Cooper, Cox, Namouz and Case 2008; Falchikov 2001). A collaborative learning environment can be achieved in a variety of ways, including Process Oriented Guided Inquiry Learning (POGIL) (Farrell, Moog & Spencer 1999; Moog 2009; http://www.pogil.org), Peer-Assisted Learning (Boud et al. 1999), Peer Instruction (Crouch and Mazur 2001) and Team-Based Learning (Michaelson and Sweet 2008). It has been shown that students benefit from collaborative learning through development of problem-solving (Robblee 1991) and critical thinking skills (Johnson and Johnson 1989). After evaluating a number of these potential teaching approaches, we came to the conclusion that POGIL was worth exploring due to its flexibility, which arises from the ability to use selected, but not necessarily all, of the features of POGIL in a classroom while still providing students with the benefits of the method.

Intervention

POGIL (http://www.pogil.org) is a student-oriented strategy where students work in small groups to engage with carefully designed activities. These activities focus on core concepts and encourage a deep understanding of the course material while also developing higher-order skills such as critical thinking, problem solving, and communication through cooperation and reflection. The POGIL method of concept discovery facilitates deeper understanding and greater retention of course material than can be achieved by traditional didactic teaching methods (Farrell et al. 1999). Members of the working group observed the use of POGIL in first year university classes elsewhere and attended workshops run by internationally known POGIL experts in order to gain insight into, and experience with, this method of teaching. We also ran focus groups with current students to hone the teaching approach we would use within FoC. The result was a completely restructured curriculum spread over three Foundations of Chemistry courses: IA, IB and a new summer course, IS. All three courses make extensive use of small group guided inquiry and online learning. The combination of FoC IA and IB covers a solid base of chemical knowledge suitable for students to continue their studies into cognate disciplines. When combined with FoC IS, a student obtains the complete spectrum of chemistry knowledge that is equivalent to the existing courses Chemistry IA and IB.

Course restructure

Foundations of Chemistry IA and IB each consist of four lecture blocks (which we have chosen to call modules) that run over a 12–13 week semester, with each module containing eight 50-minute lectures. Each module builds upon knowledge gained in the previous one (FoC IA begins without any assumption of prior Chemistry knowledge). Lectures are based on POGIL methodology, used in a modified form. A "pure" POGIL classroom involves students spending the entire time in class working on activities, with additional problems completed outside of class in the students' own time. Our modified version has each lecture starting with approximately five slides of content before students break into small groups to work on POGIL-style activities. These activities follow a prescribed structure wherein students are first presented with some information, either in the form of a diagram, table or short paragraph of text, which is then followed by a series of critical thinking questions that compel students to grapple with new concepts and encourages them to communicate with one another. During these breakout sessions, the lecturer and two teaching assistants circulate the lecture theatre answering queries. At the end of the designated activity time, the lecturer reconvenes the class to work through the answers with student input. This cycle is repeated throughout the 50-minute lecture period. The working group developed a number of POGIL-style activities to use in lectures, and a paper describing the development process of some of these has been published previously (Williamson, Metha, Willison and Pyke 2013). An example of one of these activities is included in Appendix 1.

Lecture material in FoC IA and IB is supported by one 1-hour workshop (formerly tutorial) session each week. The format uses a similar inquiry-based approach to that used in lectures to continue to encourage students to work in small groups and discuss the provided problems with their classmates.

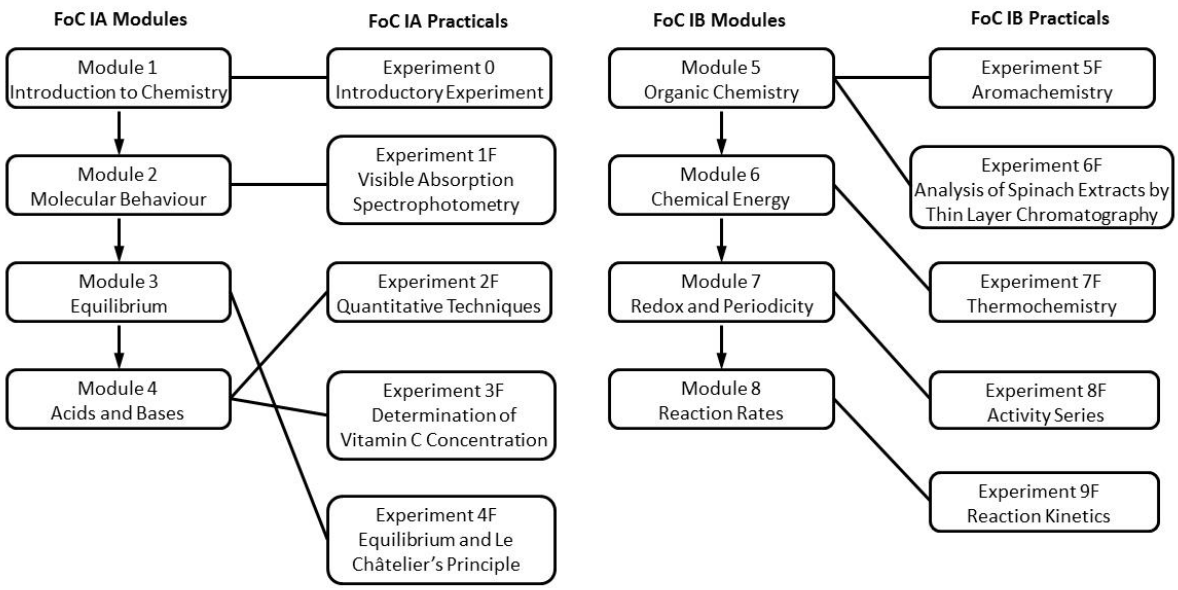

Figure 1. Module topics and practicals for the new FoC IA and IB. Boxes linked by a solid line indicate a Module and a practical with related content

Laboratory experience is an essential part of learning chemistry, especially at the introductory level. The coursework for FoC IA and IB includes five laboratory practicals each semester, which are scheduled fortnightly. All of these practicals were redesigned so that they would be conceptually and contemporaneously aligned with lecture material, so as to allow students to make immediate connections with what they are covering in lectures and the tasks they are carrying out in the laboratory. A summary of the topics covered in each module, as well as the accompanying practicals for each semester, are shown in Figure 1.

Several FoC practicals are based on practicals presented in Chemistry IA and IB (Experiments 1F, 2F, 4F, 6F, 7F and 9F), reflecting the coverage of similar content within these courses. However, the FoC versions have been extensively rewritten to provide extra guidance for students. The experiments unique to FoC (Experiments 0, 3F, 5F and 8F) were carefully developed from scratch in order to provide a practical experience for students that supported specific lecture content not currently linked to practicals in Chemistry IA/IB, or gave students extra experience with common chemistry laboratory techniques.

The order of the topics (and thus, the accompanying practicals) over the year was given careful consideration by the working group. The practical script for Experiment 0 has been included as an example in Appendix 2. Modules 1 and 2 in semester 1 (containing topics such as the periodic table, structure of the atom, intermolecular forces and bonding) were deemed core material that was needed in order for students to be able to grasp the concepts that were to follow in the rest of semester 1 and in semester 2. The content of Modules 3 and 4 in semester 1 was viewed as necessary background for the modules to come in semester 2, resulting in the order shown. Although the Chemical Equilibrium module was the third one presented in FoC IA, the accompanying practical was scheduled as the last one in that semester, to allow students as much time as possible to assimilate the material. Originally, Experiment 4F was scheduled as the fourth practical of the semester, to align with the time frame in which Module 3 was presented; however, we found that many students had yet to fully grasp the material from that module at that point, which made completing Experiment 4F difficult for these students. Delaying Experiment 4F to make it the final practical of the semester resulted in an improved learning experience for students, based on verbal reports from the demonstrators who led the practicals describing how much more comfortable students were with the material when the practical was scheduled later. Moving Experiment 4F meant that Experiments 2F and 3F now run slightly earlier than originally planned. However, as these experiments are more focussed on techniques (titration and pipetting), we have found that students handle them well despite their earlier position in the schedule.

One of the decisions the working group made early in the course restructure process was to provide students with access to as much feedback as possible, for both formative and summative tasks. Each module in FoC IA and IB has an online summative assignment that students undertake through the Pearson publishing group's online learning platform MasteringChemistry (http://www.pearsonmylabandmastering.com/au/). This system allows instructors to create assignments that provide students with instant, adaptive feedback based on the answers they have entered. In addition, MasteringChemistry assignments can be configured so that after the due date has passed, students can go back and rework any of the assignment's questions for practice without changing their original grade. Questions within the Mastering system are provided with difficulty ratings, so instructors can control the difficulty of the assignments they create depending on the questions selected.

Additional feedback is also provided to students through lecture tests. Two lecture tests are held for each of FoC IA and IB, generally scheduled around the mid-point and the end of each semester. A lecture slot is used for each test, in which students are given 30 minutes to answer 15 multiple choice questions covering the course content of the previous five weeks. The lecture tests are non-compulsory, and can be redeemed in the end-of-semester examination if a student chooses by completing the corresponding multiple-choice question section provided in the examination paper. Although the lecture tests are non-compulsory, we usually see 80% attendance at the tests, indicating that students value the opportunity to receive feedback in this way. A class results summary is posted for each lecture test, and general feedback on problem-solving approaches for questions that were answered less well is also provided to students. It was decided to make the lecture tests non-compulsory so as to provide students with a choice in how they approached their learning for the course. Some students benefit from continuous assessment, preferring to revise lecture notes as they go and working on each content section in turn. However, other students prefer to revise the entire semester's worth of content just prior to the exam and feel more confident approaching assessment in this way. For those in the former situation, the lecture tests provide a valuable source of feedback and the opportunity for continuous assessment. However, students who prefer to leave their revision until later are not disadvantaged, as they can obtain the same amount of marks by completing the "lecture test" section in the exam, and are still able to sit the lecture tests if they wish.

In restructuring FoC, the working group also wanted to review the way students would be assessed in the new courses. Prior to 2012, both semester 1 and semester 2 FoC courses were assessed through four online assignments (10% of the final course grade), practical work (20%) and an end-of-semester examination (70%). Assessment for the restructured FoC IA and IB provides students with more flexibility, the opportunity for continuous assessment, and less reliance on a final examination. The new FoC IA and IB are assessed through the two lecture tests (together worth potentially 20% of the final course grade), four online MasteringChemistry summative assignments (20%), the practicals (20%), and a final examination (40–60% of the final grade depending on whether lecture tests were attempted). Chemistry IA and IB are assessed in a similar way.

FoC IS was the Department of Chemistry's first summer semester course. Students who have completed FoC IA and IB do have some gaps in their knowledge, and the purpose of FoC IS is to bridge that gap and provide students with a pathway into second year chemistry courses. Students in FoC IS are assessed through five online assignments (each worth 9% of the student's final grade, for a total of 45%), workshop preparation (10%, based on the student's solution to a question submitted for marking to their workshop leader at the start of each session) and a final exam (45%).

The University of Adelaide summer semester is a shorter teaching period than that of the "regular" semesters, running during January and February each year. The content of FoC IS is based on material from the mainstream chemistry courses Chemistry IA and IB. Students enrolled in FoC IS spend ten days on intensive study, with each afternoon involving self-directed learning in the form of viewing a series of pre-recorded mini-lectures (created by academic staff who currently teach this content in first year) and completing activities, concept-check questions and an online multiple choice quiz. This is followed by a 3-hour face-to-face session the following morning with a workshop leader, who discusses any issues arising from the previous day's work before assisting students with additional problems provided to enhance their understanding. Small group work is a feature of these workshops, encouraging students to discuss problem-solving strategies with their peers before reporting their answers to the rest of the class. The course is delivered intensively over ten days, with the work spread out over a period of 3–4 weeks to allow students time to assimilate content.

Impact on student learning

The new FoC courses were fully implemented for the first time in 2012 (2013 for FoC IS). Student Experience of Learning and Teaching (SELT) surveys were administered for all Foundations of Chemistry courses. Course SELT surveys at Adelaide contain ten Likert questions, and courses are benchmarked according to the following criteria:

- This course has clearly identified learning outcomes.
- This course helps me to develop my thinking skills (e.g. problem solving, critical analysis).
- My learning in this course is supported by effective feedback.
- Overall, I am satisfied with the quality of this course.

Response options range from 1 (Strongly disagree) to 7 (Strongly agree) with 4 a neutral midpoint. % Broad agreement indicates the percentage of students that responded with a 5, 6 or 7. Course SELT surveys also include two open-ended response questions: “What are the best aspects of this course, and why?” and “This course could be changed in the following ways to improve my learning”. Student enrolment numbers for each course are provided in Figure 3; response rates to the SELT surveys ranged from 21–38%.

The 2012 Course SELT for FoC IA and IB (Figure 2) showed significant improvement over the 2011 courses in all benchmark questions (only % broad agreement is shown). The 2013 course SELT improvement is even more dramatic, with further gains in clarity of the course's learning outcomes, development of thinking skills, effective feedback and overall course quality. These gains showed slight fluctuations in 2014 for FoC IA, but overall student perception of course quality was maintained. The FoC IB 2014 Course SELT improved even further on the % broad agreement for the benchmark questions compared with the FoC IB 2013 survey.

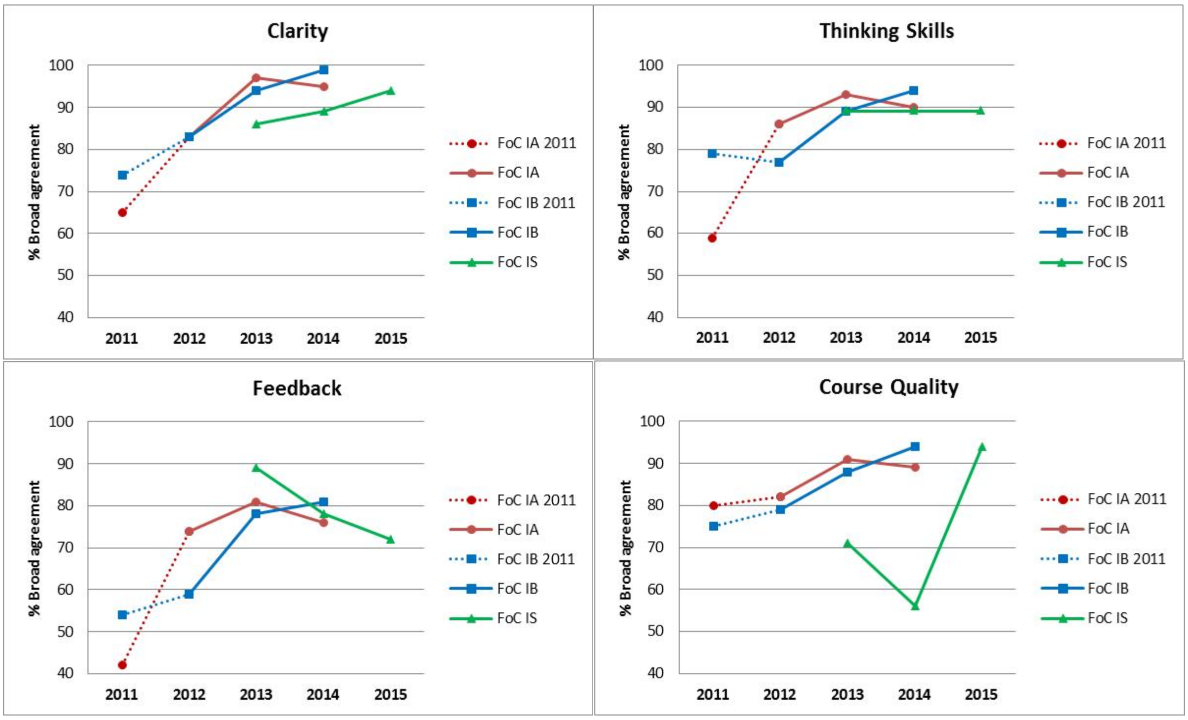

Figure 2. Course SELT benchmark question data for FoC courses 2011-2015
Note: Course SELT data for FoC IA and IB in 2011 is prior to the restructure process

Of particular note in the SELTs for all of the restructured courses is the marked improvement in % broad agreement for the question relating to the provision of feedback. In 2011, prior to the restructure, the % broad agreement for this question was 42 for FoC IA and 54 in FoC IB. By 2013, this had jumped to 81% broad agreement for FoC IA and 78% for FoC IB (and had further improved to 81% broad agreement in the 2014 FoC IB Course SELT). We believe this improvement has resulted from a combination of the MasteringChemistry online assignments, the alignment of practicals with lecture content, the introduction of the POGIL activities during lectures, and the continuation of group work into workshops, which provide multiple pathways for students to receive immediate feedback on their progress and understanding. Students commented particularly on the value of the MasteringChemistry system, as the following response, in reply to the question "What are the best aspects of this course, and why?" from the 2014 FoC IA course SELT shows: *"Mastering Chemistry Assignments because you can get instant feedback of how you are doing and redo them for practice."* Prior to the restructure, FoC courses also used an online learning platform, albeit a different one, so although it is not possible to separate completely the effects of the POGIL activities and the MasteringChemistry online learning platform on improvements in learning outcomes, most of the improvements can likely be attributed to the POGIL activities, which were not previously used in FoC courses.

Student reaction to the introduction of the POGIL activities has been extremely positive, as the response below to the open-ended question "What are the best aspects of this course, and why?" in the 2014 FoC IA course SELT demonstrates:

> *'The lectures, I think going through slides then applying what we learn straight away to some questions really helps me to understand more as it is putting it into practice while it's still fresh. It also clarifies things I struggle with going through the slides, it always*

> *becomes clear when we go through the answers and I can see where I went wrong and also see how to do it right in the future. I think it's a fantastic way to teach, I wish all my subjects did it.'*

Many of the student comments regarding the use of activities in lectures are encapsulated by the following email sent directly to one of the working party members in semester 1 2012:

> *'I also just wanted to pass on that in relation to the lecture activities - I found them to be an extremely valuable learning tool. I found concepts so much easier to grasp and remember by applying the knowledge and asking questions - than purely listening to someone for an hour. Hoping next semester will be similar! Thanks again.'*

Students also appreciated the structure of the practicals in both semesters, and frequently mentioned practicals as one of the best aspects of the course in SELT surveys, as the following comments illustrate:

> *'Practicals give students a hands-on opportunity to demonstrate skills and understanding of topics from lectures, with a decent amount of feedback to allow for improvement and better understanding of the course material.' [FoC IA 2013]*

> *'I found the practicals to be the best. I find hands-on learning more beneficial. I gather a better understanding of topics and concepts by having to do them.' [FoC IA 2013]*

> *'The practicals are what help me to understand how a concept works. Without the very good practicals I would not be able to retain information as well as I do. [FoC IB 2013]*
> *I have learnt so much. I've never done any chemistry so it has pushed me so much but I have surprisingly enjoyed it. I also enjoyed the practicals and getting a hands-on view of the things we learnt in the lectures.' [FoC IB 2013]*

The summer course, FoC IS, has now run over the 2013–15 summer semesters, with enrolments ranging from 30 to 40 students each year. The structure of the course, as outlined in the previous section, provides regular, continuous feedback and assessment to guide and monitor student progress. As seen in the SELT scores (see Figure 2 above), the students were highly appreciative of the clarity of the course learning outcomes (Q1, 2013 broad agreement = 86%, 2014 = 89% and 2015 = 94%) and thinking skills development (Q7, 89% broad agreement for all three survey years). The feedback and overall course quality were very high in 2013 (89% and 71%, respectively), but this dropped in 2014 (78% and 56%, respectively). Based on the 2014 student comments, the main concern was the intensity of the coursework, which was delivered over three weeks due to the shortness of the summer semester. For 2015, we released the course material in the University's online learning management system more than a month prior to the course's commencement date to allow students more time to familiarise themselves with the content. In addition, as many free days as possible (within the limitations of the summer semester period) were scheduled in between the workshop sessions to provide students with a greater opportunity to assimilate content during the course. These changes appear to have had an overall positive effect, with the % broad agreement for the question on overall course quality increasing in 2015 to a course high of 94%. However, the % broad agreement with the question relating to feedback dropped slightly in 2015 to 72% compared to the 2014 result of 78%, despite no changes to the way the course was delivered in 2015. While the % broad agreement for the feedback question is still relatively high for FoC IS (especially compared to the % broad agreement for the same question in FoC

SELT surveys prior to the restructure), we feel that there is room for improvement in this area. In order to provide students with increased feedback, we will introduce more mechanisms for achieving this within FoC IS in future, including practice exercises and a mid-course multiple choice test.

The inaugural FoC IS class of 2013 responded favourably in the course SELT, with comments praising the course structure and small-group learning approach, including *"It's so much better learning the information about topics on your own and at your own pace. Working in groups has been an interesting and enjoyable experience."* The FoC IS course SELT for 2014 also provided positive student comments, including the following:

> *'Several aspects of the course follow on directly from where we left off in the previous course which is good. Lots of practice material provided. Short video course content is great especially when pin-pointing problem areas.'*

The 2015 FoC IS cohort also found the course to be a valuable learning experience, as evidenced by the comment below from the course SELT:

> *'Small workshop groups was great, gave opportunity to get to know tutor and many opportunities to ask questions in [a] comfortable environment.'*

In addition to increased student satisfaction with the courses, the new FoC IA and IB also delivered better final results, with a greater proportion of students receiving distinction (D) and high distinction (HD) grades in 2012–2014 compared with previous years (Figure 3). The increase in D and HD grades suggests that more students are engaging with the course material and gaining a greater understanding of the underlying theory. Enrolment numbers are taken immediately after the census date for the courses, at which point all course enrolments are finalised.

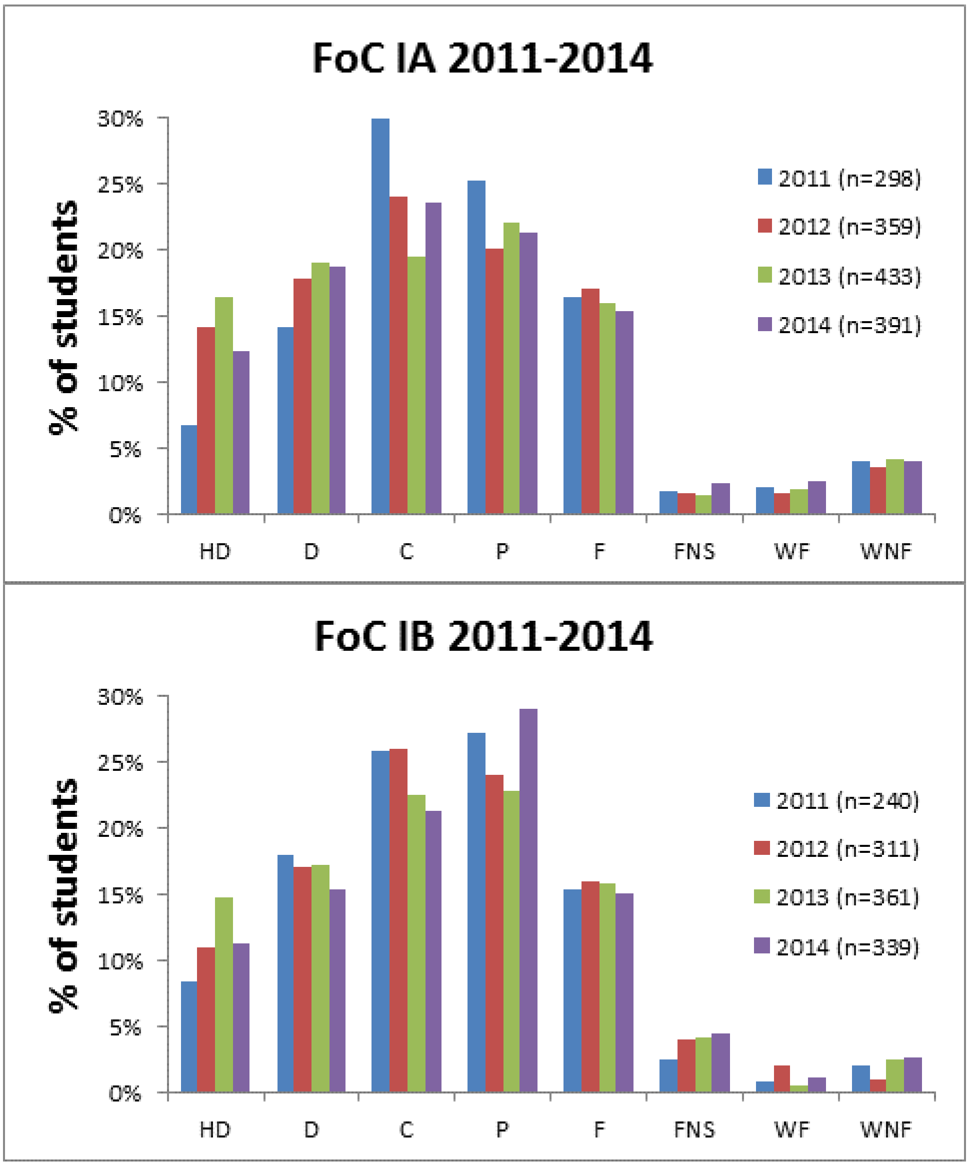

Figure 3. Grade distributions for FoC IA and FoC IB (2011-2014). **HD = high distinction (85-100%); D = distinction (75-84); C = credit (65-74); P = pass (50-64); F = fail (<50); FNS = fail no submission; WF = withdraw fail; WNF = withdraw no fail**

Students also appreciated the overall course structure, as illustrated by the comment below taken from the 2013 Foundations of Chemistry IB course SELT:

> *'There really is nothing bad to say about this course. It's the best one I've taken to date. The amount of material is spot on for balancing with other classes. There's ample support for students, the staff are really good. One module flows into another, the tutorials are very useful, the practical demonstrators are hilarious and helpful. The mastering chem modules fill in all the gaps. The critical thinking questions lead through the material really well. I genuinely think grades in this course will directly reflect the student.'*

One of the additional benefits of the new FoC structure is that we are now offering a new pathway for students who come to university with little or no high school chemistry. Of the 28 students who passed FoC IS in 2013, 14 continued on into our core level II courses, Chemistry IIA and IIB, in 2013 and of those, four enrolled in the core third year course Chemistry III in 2014, giving them the opportunity to complete a chemistry major. In 2015, the Department of Chemistry has welcomed its first Honours student to have entered through the new FoC IA/IB/IS pathway. The Chemistry Honours program at the University of Adelaide is an extra year of study, consisting of coursework and a research project, that students can undertake after completing a three-year Bachelor degree. Of the 33 students who passed FoC IS in 2014, 15 enrolled in Chemistry IIA and IIB that year. Three of these students have gone on to enrol in Chemistry III in 2015. More than half of the 2015 cohort of FoC IS have gone on to enrol in Chemistry IIA and IIB (26 out of 38 students). In addition to enrolling in Chemistry IIA and IIB, FoC IS students also enrol in the second year chemistry courses Environmental and Analytical Chemistry II and Medicinal and Biological Chemistry II (around 6-10 students per course each year). These two courses are not essential for students who wish to obtain a major in chemistry; however, they are useful for broadening students' chemistry knowledge base. It is very fulfilling to know that we have been able to instil an enjoyment and appreciation of chemistry in these "late-bloomers".

Summary and conclusions

The complete restructure of the University of Adelaide's introductory chemistry courses has resulted in the creation of three new courses, FoC IA, IB, and IS. The inclusion of inquiry-based learning in the new courses has been well-received by students, who also appreciated the level of feedback available, course structure, and overall course quality. Student performance has improved, with a greater proportion of students obtaining Distinction and High Distinction grades in FoC IA and IB than prior to the restructure. The summer semester course FoC IS provides students in the introductory chemistry pathway the opportunity to continue with their chemistry studies at higher year levels.

Acknowledgements

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References

Boud, D., Cohen, R., & Sampson, J. (1999). Peer learning and assessment. *Assessment & Evaluation in Higher Education, 24*(4), 413-426.

Bowen, C. W. (2000). A quantitative literature review of cooperative learning effects on high school and college chemistry achievement. *Journal of Chemical Education, 77*(1), 116-119.

Cooper, M. M., Cox Jr., C. T., Namouz, M., & Case, E. (2008). An assessment on the effect of collaborative groups on students' problem-solving strategies and abilities. *Journal of Chemical Education, 85*(6), 866-872.

Crouch, C. H., and Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69*(9), 970-977.

Falchikov, N. (2001). *Learning together: Peer tutoring in higher education.* London and New York: Routeledge Falmer.

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A guided inquiry general chemistry course. *Journal of Chemical Education, 76*(4), 570-574.

Johnson, D. W., & Johnson, R. T. (1989). Social skills for successful group work. *Educational Leadership, 47,* 29-33.

Michaelson, L. K., & Sweet, M. (2008). The essential elements of team-based learning. *New Directions for Teaching and Learning, 2008*(116), 7-27.

Moog, R. S. (2009). An introduction to POGIL. *Abstracts of the American Chemical Society* (p 1). Washington DC, USA: American Chemical Society.

MyLab & Mastering: Pearson (2015). Retrieved February 2, 2015, from http://www.pearsonmylabandmastering.com/au/.

Process Oriented Guided Inquiry Learning (2012). Retrieved December 16, 2014, from http://www.pogil.org.

Robblee, K. M. (1991). Cooperative chemistry: Make a bid for student involvement. *The Science Teacher*, *58*(1), 20-23.

Williamson, N. M., Metha, G. F., Willison, J. & Pyke, S. M. (2013). Development of POGIL-style classroom activities for an introductory chemistry course, *International Journal of Innovation in Science and Mathematics Education*, *21*(5), 16-30.

Appendix 1. Physical properties of alkanes POGIL activity

Activity 1.2 – How do the physical properties of alkanes change with size?

Table: Boiling point, molecular weight and physical state of selected alkanes

Alkane	No. of carbons	Molecular weight (g mol^{-1})	Boiling point (°C)	State at room temperature
Methane	1	16	-162	gas
Ethane			-89	gas
Propane			-42	gas
Butane			0	gas
Pentane			36	liquid
Hexane			69	liquid

Critical Thinking Questions

1. Complete the second column in the table, adding the number of carbons present in each alkane.

2. Describe the general trend in the boiling point of alkanes as the number of carbons increases.

3. Complete the third column in the table by calculating the molecular weight for each alkane.

4. How does the boiling point trend you described in CTQ 2 relate to the molecular weight of each compound?

Information

The boiling point of a liquid increases as the intermolecular forces between molecules increase.

Critical Thinking Questions

5. Based on your answers to CTQ 2 and 4, the information above and the data provided in the table, how do the intermolecular forces between molecules change as the molecular weight of an alkane increases?

6. Based on your answer to CTQ 4, in what physical state (solid, liquid or gas) would you predict the alkane icosane (molecular formula $C_{20}H_{42}$) to exist at room temperature? Explain your answer.

Appendix 2. Practical script for Experiment 0

EXPERIMENT 0

Introductory Experiment

(This experiment is done individually but group discussion is encouraged.)

What is the relevance of this prac…?

Part of today's prac is centred around a common laboratory compound called sodium hydroxide (shown in the picture below).

However, the questions you answer - and the methods you use to do them – in this experiment and the others that follow this semester, can be applied to any chemical compound you come across (even ones you have never heard of before). These methods will be useful for the rest of your chemistry experience and are used on a daily basis by students, researchers, academics and even your professors.

Chemists are required to be familiar with a variety of common laboratory techniques in order to be able to do their job. This experiment also allows you to build your skills in the practice of a very common laboratory technique: pipetting.

Learning objectives (remember these are different to the scientific objectives):

On completion of this practical you should have:

- Become familiar with locating elements on the periodic table
- Become familiar with identifying cations and anions (and understand what the charge is a result of)
- Linked an element's position on the periodic table with the types of compounds it forms
- Become familiar with the correct use of a volumetric pipette.
- Become familiar with the correct use of an analytical balance.
- Practised the use of the equation relating density, mass and volume.

Introduction (extra background)

There are many concepts and calculations that chemists deal with on a daily basis. Some of them are described and used in this practical; others will be featured in future practicals. These methods and skills are so ubiquitous in the career of a chemist that they are never mentioned in scientific reporting (it is assumed that everyone is competent in them) and yet all of our experimentation relies on us understanding these foundation concepts and others.

All of the material covered in Part 3 has been addressed in your lectures and can be revised in the following text chapters:

Tro, 4th Edition: Sections 1.1, 1.2, 1.3, and 1.5
Sections 3.1, 3.2, 3.3 and 3.6

This prac session gives you the opportunity to make sure you understand these fundamental concepts and can utilise them. Many of the following questions can be answered now (you won't have to wait for experimental results on the day to answer them). So whether you are concerned about the material or comfortable with it and aiming to complete the prac early, it is recommended that you attempt them before the session.

Pipetting

In Part 2 of the experiment you will practise using a volumetric pipette (25 mL) and an analytical balance by weighing the mass of water delivered by the pipette.

You should discover how successive samples differ due to experimental errors. Variations within a certain range are an inevitable and irreducible fact of life. These can be quantified by considering the possible sources of error (this will be discussed further in Experiment 2F). However, larger variations, resulting from mistakes and poor technique must be recognised and eliminated. At each check point in this script you are advised to discuss with your demonstrator the results that you have obtained. Do not be embarrassed if your results do not seem to be as precise or accurate as you would have hoped. The purpose of this part of the experiment is to convince you that your technique will affect your results and this lesson may be better learned if you have obtained poor results! This may also be the first time you have used a pipette (or even heard of one!) so do not be disappointed with your first attempts.

Density, mass and volume are related by the following equation:

$$\boldsymbol{\rho = m/v}$$

Where ρ = density (in grams per ml; often written as $g.ml^{-1}$), m = mass (in g) and v = volume (in ml). Note that sometimes "d" is used instead of ρ to represent density.

The density of water varies with temperature. Using the water density graph provided in the appendix to this manual, you will be able to convert your experimentally determined weights to volumes and consider the accuracy of the pipette you have been using.

Experimental

Drawing a diagrammatic representation of what you will do in your experiment can help you to visualise what you'll need to do during the session and also to not accidentally miss crucial steps.

Before commencing work on Part 2 you should watch the video, 'Pipetting'. You will need to equip yourself with headphones and wait until your colleagues are ready before asking your demonstrator to start the video.

Reminder - each student should work *individually*. It is important that you work carefully in order to gain worthwhile experience from this class.

PART ONE THE LAB MAP

Using the lab map provided, walk around the first year lab and locate all of the items listed. Keep your completed lab map handy for the rest of the semester.

PART TWO VOLUMETRIC PIPETTES

PROCEDURE

1 *As a class watch the video, 'Pipetting'.*

2 *Label and weigh accurately, to 3 or 4 decimal places*[1]*, three dry weighing tubes with plastic stoppers in place. Record their weights in* Table 1 *in your report book and be careful not to mix up the stoppers as their weights will vary significantly.*

3 *Place some de-ionised water in a beaker and record the temperature of the water.*

4 *Using a volumetric pipette with correct technique, transfer 25.0 mL of de-ionised water into each of the weighing tubes taking care to replace the stoppers on the correct tubes.*

5 *Re-weigh the tubes and calculate the weight of water in each tube. When you have finished with the tubes please place them on the drying rack on the bench.*

6 *Using the equation on page 2 and the water density graph provided on page 6, calculate the volume of water delivered into each tube.*

7 *Complete the rest of the table in your report book, including the calculation of your mean volume and mean deviation.*

<u>Question 1</u> – Pipetting

Express your experimental results below as mean volume ± mean deviation and compare with the manufacturer's claim (printed or etched onto the pipette you used).

Your results		±	
	volume		mean deviation
Manufacturer's claim		±	

a) What is the <u>volume range</u> claimed by the manufacturer for the pipette you used? (Subtract the manufacturer's mean deviation from the pipette volume to get the first value for the range, and add the manufacturer's mean deviation to the pipette volume to get the final value for the range.)

b) Does your <u>mean volume</u> fall within the <u>volume range</u> of the manufacturer's claim?

c) Given that the mean deviation of your results should also be taken into consideration, does your <u>volume range</u> overlap with the volume range of the manufacturer's claim?

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[1]The analytical balances that you should use are capable of weighing small masses to an accuracy of either ± 0.001 g or ± 0.0001 g. You should use the same balance each time and record **all** figures produced by the instrument, including all zeros.

<u>Question 2</u> - Density

In Part 2, you calculated the volume of water delivered by your pipette by using the density and the mass of the water in each tube. What if you needed to work out the mass of a water sample given a specific volume?

a) Calculate the mass of water in a 35.00 mL sample at 33°C.

Density is a measure of how much of a substance is present within a specific volume. Each substance has its own particular density, the value for which depends on the temperature at which it is measured. At 25°C, water has a density of 0.9970 g mL^{-1}. At the same temperature, ethanol (CH_3CH_2OH) has a density of 0.7852 g mL^{-1}.

b) Which of water or ethanol contains the most mass per volume? How did you arrive at your answer for this question?

c) Would 100 mL of ethanol weigh more or less than 100 mL of water? Explain.

d) A 250 mL glass of wine contains an average of 30 mL of ethanol. What is the mass of ethanol present in a glass of wine?

PART THREE

<u>Question 3</u> – *Elements, compounds, matter and the Periodic Table*

Sodium hydroxide (shown on page 1) is a very common laboratory compound. It has the formula: NaOH.

a) What state is NaOH at room temperature?
b) What could be done to turn the NaOH into a pure liquid (not a solution!)?
c) What elements is the compound NaOH made up of? (Hint: locate them on the Periodic Table provided on the inside back cover of your Report Book.)

Sodium hydroxide is what is known as an **ionic** compound – i.e. it involves ionic bonding and it is comprised of oppositely charged **ions** attracting each other. In NaOH the oppositely charged ions are Na^+ (sodium ion) and OH^- (hydroxide ion).

d) Which is the cation and which is the anion?

How does a sodium atom become a sodium ion:

e) How many protons does a neutral sodium atom have? (Hint: find sodium, Na, on your Periodic Table. What number on its element tile can be used to determine number of protons?)
f) How many electrons does a neutral sodium atom have?
g) What is the number of protons and number of electrons in a sodium ion, Na^+ and how does this account for the positive +1 charge?

Chemistry connections…

We know that all atoms are made up of the same subatomic particles: protons (+1) and neutrons (neutral) in the nucleus and electrons (-1) orbiting around the outside. We also know that all atoms/elements are defined by the number of protons that are found in the nucleus, which is given by the atomic number on the Periodic Table. For example, any atom in your body that has one proton in the nucleus is therefore, by definition, a hydrogen atom. If you found an atom on the other side of the universe that had eight protons in the nucleus it would be, by definition, an oxygen atom. So, can an atom lose or gain protons in order to become charged? From the question above, why can't a sodium atom, Na, gain a proton to become Na^+? What, in fact, would the species be with 12 protons and 11 electrons?

There are literally *billions* of compounds in the universe, so chemists tend to put them into groups that have similar properties or chemical activity. For example, sodium hydroxide is a compound that is known as a base. A base is a species that can gain a hydrogen ion, H^+. You will learn more about acid-base chemistry later in the semester and also use NaOH to perform an acid-base reaction in a later prac. This type of experiment is called a titration.

There are many other examples of bases, some of which are found in the table below.

h) Fill out the table using the NaOH row and your Periodic Table to help you:

Compound formula	Cation* (and name)	Anion (and name)	Name of compound	How many e^- in atom?
LiOH				Li:
NaOH	Na^+ (sodium cation)	OH^- (hydroxide anion)	sodium hydroxide	Na: 11
KOH				K:
RbOH				Rb:
CsOH				Cs:

*when determining the charge on the cation, remember that in neutral ionic compounds the positive cation charge must cancel out (be equal and opposite to) the negative anion charge.

i) Lithium, sodium, potassium, rubidium and caesium all have different numbers of electrons and yet all prefer to lose one electron to form 1+ cations. What do all of these elements have in common? (Hint: where are they on the Periodic Table?)

Appendix A

Density of water as a function of temperature – read the density to the ***fourth*** decimal place