The CASPiE Experience: Undergraduate Research in the 1st Year Chemistry Laboratory

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Abstract: *With 40 separate programs represented amongst the students enrolled in 1st year chemistry at The University of Queensland (UQ), an integrative teaching and learning framework has evolved which incorporates inductive approaches to increase the relevance of chemistry in multidisciplinary contexts. With increasing evidence of poor engagement in the practical component of the course an intervention was planned through the introduction of an undergraduate research experience based on current innovative practice in chemical education (Weaver, Russell & Wink, 2008). The solar cell laboratory research module developed in the Centre for Authentic Practice in Science Education at Purdue University was translated to the UQ context. From a cohort of 1000 students, 26 students self-selected to participate in the pilot module which replaced three conventional 'cook-book' laboratory exercises. The adaptation of the module retained the skill-building and inquiry phases of the authentic CASPiE experience. Peer-assisted study sessions replaced the peer-led team learning component of the module and students were asked to prepare an abstract instead of a practical report to maintain the weighting in assessment compared to the majority of the course cohort. A mixed methods approach was adopted for the evaluation of the learning experience including pre- and post-tests, a 'nature of science' questionnaire and interviews. Data has been evaluated through quantitative and qualitative analysis (SPSS and NVivo). Students demonstrated increased engagement in the CASPiE module and greater gains in learning from this experience than in a conventional 1st year chemistry laboratory exercise. They exhibited greater engagement through the intellectual responsibility of completing their own experiments even when they failed to get the results they expected. The outcomes of this case study are presented including discussion of the implementation and factors that emerged reflecting the success of the translation of this pedagogical strategy from the US to Australian contexts.*

The outcomes of the pilot study are informing the scale-up of the implementation in 1st year chemistry and the development of a UQ research based module for implementation in 2nd level chemistry in 2009.

Introduction

One of the goals in delivering 1st level chemistry to large diverse cohorts (>1000 students) is the provision of a series of learning activities that both engage and challenge students. However, the traditional laboratory component in these courses is often structured to address logistical and resourcing factors rather than learning objectives. Each experiment is also typically designed to incorporate opportunities for students to acquire competencies in core chemical techniques while gaining skills in critical evaluation, data processing and experimental design. The provision of traditional recipe-based experiments in which students complete white spaces in the prelab, results and post lab sections of printed handouts has evolved to reduce the cognitive load on students who may have had limited exposure to the chemical laboratory. An undesired outcome of this structure is the disengagement of students who have had significant exposure to practical aspects of chemistry during their secondary education and this often results in attrition. In addition, presentation of experiments in this format constructs an image where the purpose of an experiment is to train students in a procedure in which they have to reach the 'right' answer (Windschitl, Thompson & Braaten, 2008). This approach reinforces students' expectations that they are completing a practical demonstration of a concept taught in lectures which is how experiments are often used in the secondary context.

Undergraduate research is widely recognised as a pedagogical route to enhancing students' identities as scientists, raising students' awareness of the nature of science and improving the recruitment and retention of undergraduates (Russell, Hancock & McCullough, 2007; Hunter, Laursen & Seymour, 2006; Weaver et al., 2008). In this study, as part of a curriculum reform in 1st level chemistry through the introduction of active learning experiences, an undergraduate practical research experience was implemented as an intervention to provide an authentic practical experience. The research module comprised a three week skill-building phase where students learnt the skills required to embark on a three week research phase. Students prepared zinc oxide solid solutions through spray pyrolysis on glass substrates and then determined the impact of the solute (students selected the identity of the minor component and sought the optimal composition of the solid solution) on the band gap using UV/Vis spectroscopy. Real world connectivity was developed through examining whether their films promoted the decomposition of organic dyes representing environmental contaminants. This research module had been demonstrated as enhancing students' scientific process skills and their understanding of the nature of science (Weaver et al., 2008). An established collaboration with the designers of the undergraduate research module enabled adaption of the resources and associated evaluation instruments to the Australian context. The pilot module was very well received by the students with evidence that there were positive shifts in their scientific thinking (including the purpose of an experiment), their engagement in experimental processes and the learning community.

Methodology

The traditional practical component of the 1st level chemistry course at our institution comprises five experiments each of which is completed in a 3 hour session. All students in this study had completed the first semester chemistry course and experienced the traditional laboratory format. The CASPiE module was designed to be implemented over six sessions (three hours each) and substituted three standard experiments in the semester 2 chemistry course. Students for the CASPiE route were recruited by inviting the whole cohort to apply via an expression of interest for the 30 available places. 26 students were accepted from the 44 applicants based on their academic program (BSc students were given priority but the final group included students from Biomedical Sciences, Pharmacy, Biotechnology and Food Technology). The second requirement applied in the selection process was that students had completed the 1st semester chemistry course and achieved a grade of 5 or higher. Students were allowed to choose their own groups of three for completion of the module. The module was divided into two phases: (i) 3 sessions of skill-building where they were familiarised with the context of the study, sample processing and instrumental techniques. (ii) 3 sessions of the research phase where they planned and completed experiments based on their own observations and evaluation of their data. The CASPiE students also participated in a related PASS (peer assisted study session) in their groups where they completed pre-prepared exercises such as maintaining a laboratory notebook and identifying patterns and correlations in data. Assessment of academic outcomes was based on evidence of practical process skills via completion of a laboratory notebook and the submission of an abstract at the end of the module. The effectiveness of this intervention was evaluated through translation of existing instruments provided by the CASPiE team which included online pre- and post-tests managed through Qualtrics (students who completed the CASPiE module are designated 'CASPiE' and a randomly selected control group comprising one stream of 73 students completing the traditional practical route, designated 'traditional'). Focus group interviews (n = 4) were conducted with the participants who volunteered in response to an invitation circulated to all the students in each of the CASPiE and control groups. A nature of science questionnaire was also completed on completion of the practical course at the end of semester. Focus groups were semi-structured and typically took 50 mins.

A mixed methods approach was adopted where quantitative and qualitative data were analysed using standard statistical research software (SPSS and QSR NVivo). Statistical means and standard deviations are reported for the pre- and post-tests. Recurring themes in qualitative data were identified by two analysts independently and cross-referenced to code emerging ideas. Human Ethics approval (UQ application number 2008001509) was granted for this study.

Results & Discussion

Multiple themes relating to student engagement in learning in the laboratory emerged from student responses: understanding of the terms “theory”, “hypothesis” and the “purpose” of an experiment; the role of the laboratory tutor in the learning community; and the role of peer discourse in constructing shared ideas. In translation of a current innovative practice from the US context to the Australian context, the prior learning experiences of students and their different socio-cultural backgrounds may impact on the success of the initiative. The effectiveness of the implementation of the CASPiE research module was measured using instruments parallel to those implemented in the US tertiary context and as such the outcomes were compared to those reported by the Weaver group (Weaver et al., 2006).

The Scientific Process

Students arrive at university often with poorly developed conceptualisations of the nature of science or recognising what ‘thinking like a scientist’ is (Hunter et al. 2006; Domin 2008). The change in student perceptions of the nature of science after their CASPiE research experience was explored through focus group interviews and quantitative data (pre/post survey). Students were invited to share their ideas and understanding of the terms ‘theory’, ‘hypothesis’ and the ‘purpose’ of an experiment. The students in both the CASPiE and traditional groups frequently interchanged the terms ‘theory’ and ‘hypothesis’ revealing that they did not understand the distinction between them. A theory is “…An unproven belief or understanding of why theories are the way they are” CASPiE student.

> Scientists may have different theories first as a result of what they prefer to believe ……. However, more sufficient reasons may include that a particular scientist has found certain evidence to suggest one theory and as a result have become adamant on pursuing that theory. CASPiE student

> A theory is “just an idea that hasn’t been proven” Traditional student

> Multiple hypothesis relating to the same "concept" can exist because evidence gathered or related to the concept can be interpreted in different ways. Science is often taken as the truth, however, scientific knowledge is purely theoretical. This is why multiple hypotheses can exist. Traditional student

The confusion between theories, hypotheses and laws is well established (Williams, 2008) and indicates that the introduction for ways for students to distinguish these definitions remains an issue in the tertiary context.

CASPiE students frequently referred in depth to their own experiments and data revealing a higher level of engagement and recognition of understanding the processes related to experimentation and how their research related to the role of practicing scientists.

> I would have liked to have personally run more …. sort of refine the value we ended up getting as our like our value that we used but then just running like you know, running heaps more tests for it because we ended up only making one slide that was really successful. CASPiE student

> starting from scratch again and just improving the actual methodology and working out the actual maximum amount that can be incorporated as an actual value instead of a roundabout figure. Before you can go on and do anything further I guess you've got to get heaps more accurate results. CASPiE student

Traditional students revealed a disconnection from the experimental process and referred to the fact that they were being exposed to techniques and practicing data acquisition that may not always relate to their professional identity.

> *'I'm obviously not the research scientist but if you think about it, to experiment on something, if you decide, and you have your hypothesis, you want to start an experiment, then you need to know what you're going to do. Although we did only five pracs, in the five pracs we worked with five different equipment, let's just say, and those five different equipment might be, all five equipment need to be in experiments you need to do.'* Traditional student

> *'So like we need to know how to do titration and use this machine and that machine and that machine, it's initially, if we go into the research field, scientists need to know that in order to make his own experiments, make his or her results in the end'* Traditional student

Role of the tutor in the laboratory learning community

One of the insights that was revealed during this study was the strong shift in students' perceptions of the role of the laboratory tutor and the subsequent positive learning community that developed between CASPiE students and their tutors. The CASPiE students recognised that the tutors did not have 'the right answers' to their experiments and were present in the role of facilitators.

> they won't directly tell you know, do what, do so and so, it's kind of like they advise you and maybe like suggest we could do this. So and then it gets you thinking and if I do this, what will I get and I mean like what possibly that I could get so something like that rather than tell you the answer directly. I find it very useful because it actually helps you really get through the thinking something CASPiE student

> Oh the tutors are helpful. I mean even the ones that you seem not to particularly get along with. I mean they do give you instruction at the beginning. And stuff like that. And during the prac you sort of walk up to them and you go, where do I put this or, what do I do here? You know, just that basic. It's direction. Literally direction Traditional Student

The reduced dependency on tutors strengthened student engagement in their 'research' and built a learning community as they perceived the tutors as 'smart people' who were at the same level of knowledge as they were in their investigations. Traditional students perceived their tutors as providing instructions or setting 'barriers' in the process of the experiment, having control through knowing the 'right' answer and they revealed that the personality of the tutor played a big role in whether they had a successful outcome. These differences provide evidence that CASPiE promotes independent learning as students become less dependent on instructors and demonstrate responsibility for their experimental outcomes.

The impact of the size of the apparently smaller CASPiE group in comparison to the larger traditional group was not examined directly, However, at UQ, in the traditional laboratory the students work in separate modules which accommodate 20 students to enhance the learning environment and as such it was viewed that this factor would notbe significant.

Student discourse and the construction of ideas

Finally, in an interesting development during the traditional student focus group discussions, the role of peer discourse in enabling students to test their understanding and construct new ideas through a social interaction became evident. When initially asked to relate their understanding of the nature of science, they were hesitant and used under-developed language (refer above). Towards the end of the interview when discussing how ‘man’ has developed his scientific knowledge through experimentation they shared ideas and constructed a common understanding of theories. This is illustrated by the following sequence:

Student 1: “A theory isn’t right and it isn’t wrong. Until it’s proven it’s all a grey area really”

Student 2: I think a theory can change the more knowledge you develop, I think. So the more you test your theory I think you can really change it unless it’s tested or something new is found. And then for example, like it’s actually really hard for a theory to become fact, like actual fact because there can be so many kind of areas where we’re not 100% sure about it. What we actually know is that it’s all – like you know, for example again, going back to the Big Bang, it’s still called a theory because they can’t – although …… and stuff like that and they can do readings and figure out like compositions and stuff, like there’s all radiometric dating and everything now. But it’s still very, very hard to actually hit the nail on the head and say it’s fact

Student 3: “Theory can change as knowledge grows, as more things are disproved or proved …. You’ve got to test it until something changes”

This is evidence that students develop their understanding of concepts in socially interactive environments. Peer interactions are an important component of the CASPiE research module and dedicated PASS sessions were provided to enable students with an opportunity to meet and have discussions with each other outside the laboratory. Resources were provided for PASS leaders to develop discussion around a number of aspects of the scientific process, however evidence emerged during the interviews that these sessions had not functioned in a way that met the needs of the students. The PASS leaders were not viewed as supportive of their research efforts and students referred to their level of disinterest or negativity.

> we didn't seem to learn anything useful and the pass leaders were really negative about it, they were almost like they didn't expect us to find any results, like whatever happened just happened.

It is likely that the attitude of the PASS leaders was fostered by their lack of understanding of the experiences that their students were having as they had not completed a similar exercise themselves. The peer led sessions associated with CASPiE modules implemented at Purdue University are two hours long and as such promote the development of relationships. In this pilot module, these peer-led sessions were only one hour long and as such too short for constructive relationships to develop effectively. The CASPiE students proposed that these sessions should be structured to provide greater opportunity for them to discuss their own experiments within their groups and perhaps have activities that are more directly related to their studies. This was further evidence of their increased engagement in a research experience.

Role of learning in the laboratory

Students have a strong expectation that the laboratory experiments in their course of study should link to the concepts that they learn in lectures. This is not surprising when this is how experiments are typically used throughout their high school science experiences. The CASPiE research experience promoted a positive trend in this expectation with students recognising that, while not supporting the lecture content, the practical experience can fulfil another role. These shifts are illustrated by the data gained from student responses to questions in the pre- and post-surveys (Table 1 below).

There was a shift in reliance on the instructions (recipe book) evident in CASPiE students as they recognised that success was not dependent on the procedures (Table 1). After their research experience there was a trend towards acceptance that the instructions could guide them but did not necessarily have to be explicit. In addition, they increased their perception that they needed to understand the ‘big ideas’ behind the experiment rather than recognise a lecture concept. These results agree with outcomes from implementation of CASPiE research experiences in the US context (Weaver et al., 2006).

	Pre		**Post**	
	Mean	**SD**	**Mean**	**SD**
The lab experiences were very similar to real research.	**3.76**	1.48	**2.32**	1.16
The lab experiences made me realise I could do science research in a real science laboratory (for instance, at a college or with a pharmaceutical company)	**2.83**	1.44	**2.00**	0.82
The lab experiments presented real science to students, similar to what scientists do in real research labs.	**3.10**	1.35	**2.00**	0.82
I think that the lab experiments helped me understand the lecture material.	**2.83**	1.36	**3.26**	1.41
Having the opportunity to use chemistry instruments helped me learn course topics.	**2.64**	1.22	**2.58**	1.07
The concepts covered in the laboratory were relevant to the real world.	**2.30**	0.72	**1.95**	0.85
I was able to be successful simply by following the procedures in the lab manual.	**2.21**	1.13	**2.95**	1.65
I needed to understand the big ideas behind each experiment in order to do well.	**2.14**	1.21	**1.89**	0.66
The instructional materials (lab manual) provided me with explicit instructions about my experiments.	**1.96**	0.96	**2.42**	1.30
The instructional materials (lab manual) provided me with sufficient *guidance* for me to carry out the experiments.	**1.96**	1.04	**1.84**	0.60

Table 1: Changes in student perceptions as a result of the CASPiE research experience (Six point scale: 1 = Strongly Agree, 6 = Strongly Disagree)

Traditionally students expect that the laboratory repeats and reinforces lecture material (Pickering, 1987; Russell & Weaver, 2008). It is evident that the undergraduate research experience does not fulfil that role either but the benefits of the reduced reliance on instructions, increased independence and gains in the understanding of scientific processes reduce these expectations.

Summary

Through implementation of the CASPiE undergraduate research experience in 1st year chemistry, new insights were gained into the conceptual development of students ideas relating to the role of the experiment in learning. Overall, the opportunity to participate in a more active learning environment resulted in students increasing their understanding of scientific thinking and they demonstrated increased engagement and responsibility for their experimental outcomes. The learning community became more positively structured as the students’ reliance on their tutors was reduced. The outcomes of the pilot study are informing the scale-up of the implementation in 1st year chemistry and the development of a UQ research based module for implementation in a 2nd level chemistry course in 2009.

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