RESEARCH DIRECTIONS

Opportunistic use of students for solving laboratory problems: Twelve heads are better than one

Jennifer Ann Jean Burnham

University of Sheffield, UK

Abstract

A simple framework to make use of undergraduate students as a resource in solving problems has been trialled. Student volunteers were provided with symptoms of a problem and given free rein to interpret the problem for themselves. A pre-laboratory planning workshop facilitated constructions of good experimental designs and repeated referral of students to research aims encouraged them to act with purpose. The production of a written report enabled assessment of the interpretation of results and easy extraction of data for subsequent meta-analysis. The problem arose from a part of the undergraduate laboratory course, therefore, the theoretical and skill levels were appropriate for the level of the students. The results show that students did good quality experiment work. The need for teaching support is noted. It is suggested that this approach has benefited the students by giving them research experience. The benefit to me as the 'client' has been a wealth of experimental data and insight into the chemistry from unexpected analyses of results by the students. A preference for group working is noted.

Keywords: Teaching laboratory, undergraduate research, problem solving, consultancy, action research

Introduction (Plan)

I do not think it controversial to assume that students arrive at university as intelligent, creative people, lacking in specific subject-knowledge, and inexperienced in the skills and attitudes of

Corresponding author:

Dr Jennifer Ann Jean Burnham, Department of Chemistry, University of Sheffield, Sheffield S3 7HF, UK
Email: J.burnham@sheffield.ac.uk, Phone: +44 (0)114 222 9488

their chosen discipline. Increasingly at my institution, the potential of undergraduates is being harnessed during their studies. For example, Storying Sheffield (University of Sheffield 2010), the Freelaw legal advice clinic (University of Sheffield 2008), and the Global Engineering Challenge project (Horn & Murray 2012) use students to gather and interpret stories, handle clients, and solve Third-World resource problems respectively. These projects capitalise on the potential inherent in students and the students benefit from applying their skills and knowledge to the real world.

In a traditional chemistry undergraduate course, students are given few opportunities to venture outside the confines of taught material with the exception of industrial placements and final-year research projects. For Hofstein & Lunetta (1982), the laboratory holds a 'unique' place in education, enabling students to engage with investigation and inquiry. Moreover, students are increasingly being given research and inquiry or problem solving experience at early points in their undergraduate programme (see, for instance, Cacciatore & Sevian 2009, Ford *et al*. 2008, Mc Donnell *et al*. 2007 and Tsaparlis & Gorezi 2007). These examples have been incorporated into the curriculum with appropriate decisions taken as to whether the experimental direction and outcome should be known and predictable or not. In contrast, I have been unable to find mention in the chemistry literature of the idea of using students in a responsive mode of consultancy, solving chemistry problems of a genuine nature, although I suspect its *ad hoc* use is widespread.

In my undergraduate teaching laboratory, the choice of expository or verification "experiments" (Domin 1999) has been a pragmatic one based on large student numbers and limited resources. This choice does not sit comfortably with my teaching philosophy, which holds that students are intelligent and creative, with valid ideas and a worthwhile contribution to make. I place a high value on teaching students to think like chemists, which means giving them the opportunity to do genuine research. It therefore seems to be the right thing to do, when suitable problems arise, to turn them over to the students to solve. This provides students with experience of research and allows them to use their intelligence and creativity to investigate novel problems. In addition to the ideas and insight they bring, use of students is time-efficient because multiple experiments can be run in parallel. The difference between this strategy and the inclusion of inquiry in the curriculum (see, for example, Cacciatore & Sevian 2009) is its spontaneity, because the main curriculum retains the original (expository) teaching style.

This paper will examine the implementation of a framework for use in problem solving activities and will describe the outcome, analysing the effect on students' ability to experiment and the benefits to me as the problem owner.

Framework

Student volunteers receive a description of the symptoms of a problem, with minimal guidance and direction as to the possible areas of investigation, several weeks in advance of a pre-laboratory preparation workshop. The purpose of the workshop is to enable the students to design a good and safe experiment. The same dedicated facilitator is present throughout the planning and laboratory work to keep the students focused on the aims of their experiment. Assessment is by report to show students' interpretations of results as well as to provide easy access to these for subsequent collation purposes.

Methodology (Action)

This work followed the practical action research methodology sited within the qualitative research paradigm as described in Cohen *et al*. (2007) and was carried out according to the guidelines of conduct for ethical educational research (BERA 2011). To avoid reactivity effects and undue pressure on participants from my dual roles as teacher and researcher (Cohen *et al*. 2007), interaction between the participants and the study was limited to the normal interaction between students and their work; no supplementary interviews or member-checks were performed. Validation of the research was therefore only available through triangulation of the evidence (Guba & Lincoln 1981). The authenticity of the research has been gained by comparison with practice as described in the literature.

Practical action research requires that the values underpinning the research are acknowledged from the start (Wallace 1987). This research is built upon the belief that students have underestimated and unrealised potential, although they lack expertise in some areas, and upon educational values that place great importance on training students to think like chemists. The assumption being tested is that students can perform good experimental work provided that the conditions are appropriate for their levels of skill and knowledge.

During the academic year 2011/12, undergraduate students were given the option of doing some inquiry experimentation in the final two weeks of a five-week Level 2 inorganic chemistry laboratory cycle. The timing was selected to allow the students maximum time to acclimatise to the laboratory setting. Volunteers were sought from among the

doi:10.11120/ndir.2013.00003

larger laboratory cohort so that time would not be wasted motivating students to engage with the problem. The volunteers were given a description of the symptoms of a problem that had arisen with one of the teaching laboratory experiments, several weeks in advance of a four-hour pre-laboratory planning workshop. The problem had not been investigated prior to the work and no exploration of the symptoms had been undertaken. Written guidance was limited to an outline of the task being set (to define a research question, devise an experiment, and scrutinise results to see if they could answer their question) and a recommendation to investigate the permutations of the experiment available in the literature and online prior to the workshop. The pre-laboratory planning workshop was essential for controlling the selection of experiments in order to prevent the students attempting anything unnecessarily hazardous. Students were permitted to work individually or in groups to allow them flexibility in experimental design. They designed their experiments in the workshop and executed them in the subsequent laboratory sessions. Assessment of the students' work was done by report to allow for variation in experimental content and also for easy extraction of ideas and results for my own use.

Twelve students participated in the study, opting to work as two groups of three and three groups of two. Evidence was gathered from their experiment reports, learning-evaluation forms, and the student evaluation of the course, as well as from my personal observations and reflections on the process.

Results

Chemistry tackled

The symptoms of the problem suggested that reaction products were contaminated with an acidic liquid. Three of the five groups chose to investigate the problem at the reaction work-up stage. One group performed spectroscopic analysis of reaction mixtures following work-up by varying amounts of alkali, one group compared product yields following work-up by varying amounts of alkali, and one group compared two different methods of acid neutralisation. The other two of the five groups chose to investigate the symptoms of the problem by changing the parameters of the product-separation. In total, eighteen separate syntheses were performed under rigorously controlled reaction conditions.

Experiment reports

All twelve participants submitted experiment reports. Content analysis was performed on these reports and codes assigned identifying the problem, experiment aims, how these aims were addressed, the conclusion of the aims, and any further work suggested. Student inexperience in report writing made it necessary to infer meaning in a few places where the student had been unclear. At the end of this process, the codes were checked to see if they were consistent and whether the early code assignment was correct. Reducing the reports to their component parts revealed underlying structure and enabled comparison.

All of the reports showed a good understanding of the permutations of the chemistry. Six students picked a specific part of the original problem to look at, five produced a more general retelling of it, and one did not state a problem. Ten of the eleven reports stating a problem had an aim related directly to the chosen problem and eight had a secondary or tertiary aim unrelated to the problem. The quality of reports varied from excellent to "not great", reflecting the report writing skills of the students rather than a lack of understanding of the point of their experiment. All twelve of the reports showed students had planned, acted and concluded in a coherent fashion for at least one of their stated aims.

Learning Evaluation Forms

Ten students submitted learning evaluation (LE) forms reflecting on their activities and a similar content analysis was performed on these. Nine of the forms reflected on the single experiment and one on the five-week laboratory cycle. Students were instructed to list activities in order and so experimental activities were listed in logical order by all. The nine forms showed students had performed all activities associated with experimentation (research, planning, execution, analysis, reporting). Eight forms mentioned that one of the activities was new to them. The novel activities were planning/designing the experiment (five students) including one mention of the "freedom" to plan and another of the novelty of understanding what was going on; writing in a new report style (one student); and a visit to the periodicals library (one student), which was found to have been a profitable experience. Nine forms attest to some research or reading having been done prior to the planning workshop. Comments on the report writing process varied from challenging or difficult (five students); time-consuming or long (five students); difficult to focus on aims (three students); enjoyable (two students); and easy due to familiarity with the style (one student). Eight forms included emotional responses to a "How did you find it?" prompt. These were classified as associated with positive emotions (enjoyable, interesting, good, useful; five students) and with negative emotions (daunting, didn't enjoy, stressful, horrible; four students), including one student expressing both (interesting pre-lab workshop, horrible write-up).

Personal Observations

The students were excited about the opportunity to investigate the problem. Upon receipt of the initial problem description, one student commented on the fact that this was “proper” research. Students came well-prepared for the pre-laboratory planning workshop: research into possible solutions had been done and most had some ideas of what they wanted to try. The workshop was vibrant and enjoyable with all students contributing thoughtfully to the experimental design process.

Much time and effort were expended in the first hour of the workshop getting students to consider how their proposals would address the specific problems they had identified. It took them time to focus on a single objective for their experiment as well as to understand how to design an internally consistent experiment. Similarly, in the early stages of the laboratory sessions, they asked numerous “Should I do XXX?” style questions to which I responded “Will doing XXX help you answer your research question?”

Students worked in groups of two and three with all members contributing ideas and theories to the discussion; the design of experiments was such that all group members performed at least one reaction; and groups seemed to be acting as genuine teams.

By the end of the workshop, students were focused on their task and in the later stages of the laboratory work they appeared to be acting purposefully. Rather than asking me what they should do, they were telling me, and explaining the rationale behind their decisions. With one exception, by the end of the laboratory work the students were thinking logically and were focused on their research aims.

Student Feedback

In 2011/12, the end-of-course student feedback took the form of free-response comments. Four comments mentioned this experiment work. Two said that it had been enjoyable, two appreciated the opportunity to do some experiment design, and one of these said that it was good to think about the chemistry of the reaction.

Discussion (Evaluation)

Although content analysis is a qualitative method, it can be used in a semi-quantitative way to determine relative importance (Guba & Lincoln 1981). I have adopted this approach when looking at the balance of responses. In line with the methodology of action research, the discussion will first address the assumptions of the research. It will then look at the evidence for experimentation, my influence, and the benefit to me.

Assumptions

The assumptions of the research were that students would be engaged from the outset, that they would have adequate subject knowledge and technical skill for the level of chemistry, and that the challenge for them would lie in carrying out the inquiry itself. The quantity of pre-workshop reading and research, coupled with my observations from the workshop, support the assumption that the students would be engaged from the outset. This is presumably because they were self-selected, having volunteered to take part in the project.

The assumption that students would have adequate subject knowledge and technical skill for the work was based on the fact that the experiment they were investigating was one they would normally have encountered at this point in the laboratory cycle. There was no evidence that they were inadequately equipped. In the end, students demonstrated a surprising amount of aptitude in advance of their level of study by consulting the primary literature, with one student going so far as to comment on the profitability of that experience.

The final assumption was that the students would find the experiment design challenging and it was for this reason that the pre-laboratory planning workshop was run. As discussed below, the evidence shows that experiment design was new to the students and that they needed guidance and support in the initial stages in order to do it properly (i.e. to design and execute an experiment that was fully consistent with both the aims and the problem under investigation).

Evidence for Experimentation

The starting point of scientific experimentation is that the world is an ordered place and observations can be used to predict future behaviour (Hand 1999). Science uses framework theories to generate hypotheses that can be used for prediction (Dunbar 1995). Good experimentation, therefore, needs to start with an investigation of the background of the area of interest. The evidence from the LE forms and my observations shows that the students followed the recommendation to do this, despite being unfamiliar with experimental design work. In line with their unfamiliarity, students did not start the pre-laboratory workshop with an experimental frame of mind and they needed help and guidance in order to begin to make informed decisions about the process with an eye to their goal. Bruck & Towns (2009) have highlighted that it is extremely difficult for students to make the transition from expository to investigative-style work and the evidence is that the pre-laboratory workshop and in-lab facilitation assisted with this process. The experiment reports showed experimental structure with logical and coherent flow from aims to conclusions, clearly demonstrating that the students had arrived at a point where they had understood the purpose and reasons for their actions. One student went so far as to comment on their LE form on the novelty of that understanding. This evidence strongly suggests that the students have learned about genuine experimentation (i.e. research) through this work. It is implied in the belief of Mc Donnell *et al.* (2007) that student participation in mini-project work prepares them for final-year undergraduate research project work; these results are consistent with this belief.

Student Curiosity

Comparison of the data shows evidence for student curiosity. Students came to the workshop with ideas of areas to investigate and eight reports included interesting side-avenues of investigation, which, together, show the desire of students to investigate, suggesting they are curious. The normal laboratory programme of expository experiments does not give students the 'freedom' to design their own experiments and Parker Siburt *et al.* (2011) reported that students were reluctant to manipulate provided problems, even when instructed to do so. In contrast, my students appear to have been empowered to be curious and creative and they responded well, with many going further than the brief and exploring additional lines of inquiry. Some of the most significant developments in chemistry have come about by following up on the unexpected and, because I want students to learn to think like chemists, I find it reassuring that, when they have the opportunity, students can indeed follow up on the unexpected.

Evidence of my Influence

Because the qualitative researcher is part of the setting, the dual roles of teacher and researcher can have reactivity effects on participants and on the research itself (Cohen *et al.* 2007). Quantification of my impact is not possible. However, an impression can be gleaned from a qualitative consideration of my involvement in the study.

I was very excited at the opportunity this work presented to the students. I was genuinely interested in the problem, and I had a stake in the solutions because the problem was something I needed to investigate for myself. I believe my enthusiasm encouraged the students and contributed to the vibrancy of the pre-laboratory workshop. With the exception of one student comment on the dispiriting nature of a negative result, the students did not appear demotivated at any point and several of them reported having enjoyed some or all of the process. Because of my interest in the outcome of the work, I took considerable interest in all the results, even the negative ones, which placed greater importance on them than in the typical experience of an expository experiment.

I do not believe students would have written good experiment plans without me applying the brakes to their enthusiasm in the early stages and repeatedly refocusing them on the aims of their experiment. However, despite my influence, I did not have complete control of the students' actions. Eight experimental reports contained additional aims, showing students were not constrained into linear thinking. The almost equal division of specific problem identification and retelling of the original problem suggests that the pre-laboratory workshop did not influence the interpretation of the original problem. Participants produced a variety of reports with one being exceptionally tightly focused on the primary aim of the research and others having secondary and tertiary aims, as discussed above. Taken together, this evidence shows that I had a positive influence on the pedagogical success of the project work in that students learned about experimentation and had the choice of how to tackle the chemistry.

Mc Donnell *et al.* (2007) believe that students who have had experience of experimental work adapt more quickly to their final year project than those who have not. They did not say, however, that the students required no assistance in making the transition. Given the large teaching resource required for inquiry and problem-based experimental work (for example, Cacciatore & Sevian (2009), eight or nine students per experiment; Iimoto & Frederick (2011), four to nine students to two staff; Mc Donnell *et al.* (2007), three or four students to one staff; Tsaparlis & Gorezi (2007), four students to two staff), it is probable that the extra facilitation I provided contributed to the quality of the experimental work. My observations demonstrate that work is required from both students and a facilitator when students design experiments for the first time.

The Benefit to Myself

The students' chemistry has been of enormous benefit to me as their "client". Five separate, controlled experiments investigated a variety of aspects of the chemistry of the problem and resulted in spectroscopic and analytical data from eighteen separate syntheses. The laboratory work of twelve people over two 10.5 hour laboratory sessions would have taken me several weeks to do myself. In addition, in turning the problem over to the students, I gained the insight and ideas of twelve minds. Because they applied concepts from their recent physical and organic chemistry lectures as well as from inorganic chemistry, the direction of the analysis and evaluation of results were unexpected and gave me unanticipated insight into the underlying chemistry. I now understand the parameters of the problem and know enough to be able to write a solution. I would not have learned this much about the chemistry on my own.

Conclusion (Reflection)

This work has confirmed the assumption that students can perform good experimental work provided the conditions are appropriate. It has shown that Level 2 students have the curiosity necessary for experimentation and also that (even) motivated and engaged students need to be assisted in designing their first experiment. Genuine experimental work has often been reserved for the final-year research project. However, the present work has shown that students at a lower level respond well to the opportunity. A note of caution: the students in the study were volunteers and were all keen, engaged, and motivated from the start; this might not have been the case had I involved the whole class.

The resource implications of including experimentation work for large numbers of students can be prohibitive, which is one reason why the expository style of laboratory teaching persists (Domin 1999). Comparing the time invested in this work to the time saved by using students to investigate the problem well illustrates the benefit of giving such a problem to students to investigate. Undertaking this project work involved a small investment of time on my part in the form of the four-hour pre-laboratory preparation workshop and the requirement to be present during the laboratory work alongside the need to be flexible in assessing the students' work. However, this is trivial when compared to the amount of time I would have needed to spend doing this quantity of investigative work myself. In addition, I have benefited from the knowledge and insight of the students and have a better understanding of the chemistry of the problem than I would have been able to gain on my own.

An unexpected result of the study was that all the students chose to work in groups. Group work has been criticised for allowing one student to sit back whilst another does the work (Magin 1982) but this was not apparent here. Evidence for the motivation of students to choose to work in groups was not gathered but some speculation is possible. Chemical research sits within the scientific research paradigm where control of variables is paramount. Perhaps, when students considered their options in advance of the pre-laboratory preparation workshop, they came to the conclusion that they would obtain meaningful results only if they controlled the variables by doing a comparative study. The available time meant that reactions in a comparative study would need to run in parallel, which in turn would require multiple workers for one "experiment". All of the experiment designs adopted the comparative study model and discussion in the pre-laboratory preparation workshop did not enter into alternative models of experimentation. It must have been unconsciously accepted by all (including me) that comparative studies were the correct experiment methodology to use. Because I did not challenge this assumption, group work was an inevitable result. Papers that consider group work report a favourable response by students (for example, Magin 1982, Tsaparlis & Gorezi 2007) but there seems to be no literature interrogating the motivation and preference for students adopting group work in the laboratory. This work has shown that group work can be done well and that a study looking specifically at group working dynamics would be informative.

Acknowledgement

This work formed part of the dissertation work of an MEd in Teaching and Learning in Higher Education at the University of Sheffield.

References

BERA (2011) *Ethical Guidelines for Educational Research*. London: British Educational Research Association.

Bruck, L.B. and Towns, M.H. (2009) Preparing students to benefit from inquiry-based activities in the chemistry laboratory: guidelines and suggestions. *Journal of Chemical Education* **86** (7), 820–822. DOI: 10.1021/ed086p820.

Cacciatore, K.L. and Sevian, H. (2009) Incrementally approaching an inquiry lab curriculum: Can changing a single laboratory experiment improve student performance in general chemistry? *Journal of Chemical Education* **86** (4), 498–505. DOI: 10.1021/ed086p498.

Cohen, L., Manion, L. and Morrison, K. (2007) *Research Methods in Education*, Sixth Edition. Abingdon: Routledge.

Domin, D.S. (1999) A review of laboratory instruction styles. *Journal of Chemical Education* **76** (4), 543–547. DOI: 10.1021/ed076p543.

Dunbar, R. (1995) *The Trouble with Science*. London: Faber and Faber.

Ford, J.R., Prudenté, C. and Newton, T.A. (2008) A model for incorporating research into the first-year chemistry curriculum. *Journal of Chemical Education* **85** (7), 929–933. DOI: 10.1021/ed085p929.

Guba, E.G. and Lincoln, Y.S. (1981) *Effective Evaluation: Improving the Usefulness of Evaluation Results Through Responsive and Naturalistic Approaches*. London: Jossey-Bass.

Hand, R.J. (1999) Science education: consensus versus critique. *Teaching in Higher Education* **4** (4), 501–510. DOI: 10.1080/1356251990040406.

Hofstein, A. and Lunetta, V.N. (1982) The role of the laboratory in science teaching: neglected aspects of research. *Review of Educational Research* **52** (2), 201–217.

Horn, R. and Murray, P.B. (2012), *Global Engineering Challenge: A curriculum innovation to inspire rather than assess*, 4th International Symposium for Engineering Education, 19–20 July 2012, Sheffield, UK. Available at http://isee2012.group.shef.ac.uk/docs/papers/paper_41.pdf (accessed 10th June 2013).

Iimoto, D.S. and Frederick, K.A. (2011) Incorporating student-designed research projects in the chemistry curriculum. *Journal of Chemical Education* **88** (8), 1069–1073. DOI: 10.1021/ed1011103.

Magin, D.J. (1982) Collaborative peer learning in the laboratory. *Studies in Higher Education* **7** (2), 105–117. DOI: 10.1080/03075078212331379191.

Mc Donnell, C., O'Connor, C. and Seery, M.K. (2007) Developing practical chemistry skills by means of student-driven problem based learning mini-projects. *Chemistry Education Research and Practice* **8** (2), 130–139. DOI: 10.1039/B6RP90026G.

Parker Siburt, C.J., Bissell, A.N. and Macphail, R.A. (2011) Developing metacognitive and problem-solving skills through problem manipulation. *Journal of Chemical Education* **88** (11), 1489–1495. DOI: 10.1021/ed100891s.

Tsaparlis, G. and Gorezi, M. (2007) Addition of a project-based component to a conventional expository physical chemistry laboratory. *Journal of Chemical Education* **84** (4), 668–670. DOI: 10.1021/ed084p668.

University of Sheffield (2008) *What is FreeLaw?* Available at http://lodgenews.group.shef.ac.uk/freelaw/ (accessed 6 June 2013).

University of Sheffield (2010) *Storying Sheffield*, available at http://www.storyingsheffield.com/ (accessed 3 June 2013).

Wallace, M. (1987) A historical review of action research: some implications for the education of teachers in their managerial role. *Journal of Education for Teaching: International Research and Pedagogy* **13** (2), 97–115. DOI: 10.1080/0260747870130201.