Evaluation of a student-centred approach to first-year undergraduate engineering laboratories

Norrie S. Edward
School of Engineering, The Robert Gordon University, Aberdeen, Scotland
E-mail: n.edward@rgu.ac.uk

Abstract Published evidence suggest that laboratories allow little delegation of control to the students. We gave first-year undergraduates almost complete control of a laboratory with intensive tutor support. Staff believed the activity to have been welcomed by the students. Evaluation provides far from convincing evidence for this. Explanations are suggested.

Keywords delegation of control; evaluation; laboratory; student-centred

It has been shown in published surveys that in general undergraduate laboratory practice involves students in following prescribed routines.[1] It has been suggested that the understanding which would be gained by the students would be enhanced if control of some or all aspects of the conduct of practice were delegated to them. This paper evaluates an attempt to introduce essentially complete control of a laboratory to first-year students. Lest it be thought that this was overambitious, two riders are made at this juncture. First, very intensive staff facilitation was provided. Secondly, the laboratory dealt with evaluation in scientific terms of familiar kitchen appliances. The students were provided with broad objectives as detailed below. Beyond that, decisions on how to conduct the activity and how to analyse the results were made by the students. After completion and reporting the students were surveyed about their perceptions of the experience. The results of these surveys are evaluated.

Student groups and methodologies

The students were taking a module called Technology 1 which was intended to give an introduction to basic technical concepts. The section being assessed in this activity dealt with basic thermodynamic concepts such as heat transfer, thermal capacity etc and the properties and selection of materials. The group was a composite class from five different courses. These ranged from Design for Industry, an Art School-based course, to Artificial Intelligence and Robotics which was based in the School of Electronic and Electrical Engineering. The educational background of the students was also very mixed. It ranged from students whose highest science qualification was Scottish Standard Grade Biology to others who had completed Sixth Year Studies Physics. Some considerable difficulty had been experienced in teaching such a disparate group. Here is not the place to discuss whether a different approach to teaching might have been adopted. The modular approach throws such classes and students together and approaches such as peer teaching might have been attempted.

A concern associated with such diverse levels of understanding was that the assessment, which was required to be the same for all, should both be within the capabilities of and be motivational for all students. A laboratory approach was chosen. We decided to use familiar objects which all could relate to. The expected work content had to be relatively basic, both so that those without a physics qualification could cope and because of the relatively limited time for conducting experimental investigations. Given these criteria we decided that, to avoid trivialising the activity, we would delegate control of the exercise to the students. We provided only a broad aim and then asked the students to devise their own approach.

The laboratory was conducted in groups of around six which the students themselves selected. Each group was given one or more kitchen electric heating or cooling device. Their broad objective – all the initial guidance they were given – was to investigate the device(s) in terms of thermodynamic principles and materials properties and selection. They were required to formulate specific objectives, an experimental plan indicating how they proposed to achieve these objectives and a hazard analysis and risk minimisation exercise. All of these had to be approved by a staff member before they were allowed to proceed. This was not quite the 'sink or swim' predicament it might sound. The five staff members present worked with the groups. Although they did not suggest any solutions they helped them to ask questions about what would be useful information to establish about the products, what data could be acquired from the appliances, what additional equipment they would need and how they might interpret the results. A typical plan is presented in Fig. 1. (Note that this is a summarised version of what in fact was written in the first person plural and somewhat less technically.)

Two points may be of interest at this point. Some groups started off with much more elaborate plans than others; one even had to scale back their plan due to time constraints. Some groups extended their plans as their experience and discussion suggested further avenues of useful investigation. It will be obvious from this that these were, to use Clow's terminology, laboratory experiments, not exercises i.e. almost complete responsibility for their conduct was delegated to the learners.[2]

The activity was supervised by a technician, a research student and three members of academic staff. Their brief was to work closely with all groups and to encourage them to use their own knowledge and skills to decide what they would investigate and how they would conduct the laboratory and how they would interpret the results. This was achieved largely by encouraging them to respond to questions about the activity and to reflect on the answers they came up with. Clearly this allowed the discourse with those with a less technical background to offer more detailed guidance. A typical question was: 'Will a time based on when the thermostat opens be accurate?'. When students decided it was not necessarily so they were then asked if there might be a better way of measuring the time to reach boiling temperature.

Students were expected to maintain an individual logbook of the conduct of the investigation and were given an individual mark, worth 60% of the total at the end

Appliances : Three kettles of the same wattage but different materials

Objectives set:

1. To establish the thermal efficiency of each kettle
   - ➢ With each kettle full
   - ➢ To record the cooling rate of each of the kettles after boiling
   - ➢ To establish the surface temperature of each kettle immediately after boiling

Procedure:

The kettle would be weighed empty. A measured quantity of water equal to its full capacity would be poured from the tap into the measuring jug. The water temperature would be measured. When the water had been transferred to the kettle one member with a stop watch would give a countdown and another would switch on the kettle. The stopwatch would be stopped when the thermostat clicked out. The final temperature of the water would be measured (this after staff questioning as to whether 100^{o}C could be assumed). The surface temperature would be measured. The kettle would then be allowed to cool and the temperature taken every 30 seconds to establish the cooling curve.

Equipment needed : Measuring jug (note an accurate scale was available but the students did not request its use), 0–100 ^{o}C mercury in glass thermometer, digital solid state thermometer, stopwatch.

Hazard analysis:

- ➢ hot water being carried to the sink for emptying – take care and warn others
- ➢ electric leads – take care not to have them trailing and watch during conduct
- ➢ take care when measuring temperature to avoid scalding
- ➢ be specially careful in use of mercury in glass thermometer and do not attempt to retrieve mercury in the event of breakage (this item required instruction by staff)

Analysis: Efficiency would be calculated using assumed specific calorific value of water, known temperature rise and measured mass of water to get heat in boiled water. Time to cool would be compared to look at effectiveness and properties of materials. Selection of materials would consider what an 'ideal' material would be and then discussion of why each of the three was chosen.

Fig. 1 *A typical plan.*

of the session. The following week the groups were asked to do an oral presentation of their findings and this provided the remaining 40%. Peer moderation was not used. The presentations were used as a forum for discussion with the intention of helping all of the class to learn from the findings of each of the experiments. The 40% mark included consideration of questions asked and answered.

Evaluating the experience

Student reactions

Students were issued with a questionnaire in class, immediately following their presentations. Not all students were present by this time as two groups, some of whose members had part-time employment, had left early. The 49 responses therefore represented an overall 79% response from the 62 questionnaires issued. The precise breakdown of the response rate by course is not known. No formal interviews were conducted but student reactions were solicited informally and written up at the earliest opportunity. The questionnaire consisted of just six questions relating to the student's perceptions of the experience gauged. A typical question was: 'Please mark the scale to indicate whether you prefer to devise your own procedure or to be given the procedure to follow'. The scales were continuous although in the presentation of results below they have been processed into 5-point scales for clarity.

The diversity of the students' perceptions of the experience is the first impression revealed by the analysis of the responses. In all, 49% of students would have preferred the objectives to have been given, against only 29% who preferred to be allowed to decide them for themselves. On the other hand, 39% preferred the freedom to choose the procedure while only 29% would have liked to have been told what to do. Analysis of the results showed that the respondents were relatively evenly balanced between those who would have liked guidance and those who preferred to work it out for themselves. Slightly more students had enjoyed the delegated control approach but almost half declared no strong inclination to either approach. They were similarly fairly evenly balanced between those who thought they had learned more as a result of the delegated control and those who thought they would have learned more by conducting a controlled experiment.

The composite measures computed by combining the scores and rescaling suggest that overall the students tended to favour controlled laboratories. The first of the two

TABLE 1 *Summary of students' responses to questions on their reactions to the activity*

	–2	–1	0	+1	+2	Average	Total
Objectives – given or select	7	17	11	8	6	–0.26	49
Procedure – given or select	6	8	16	10	9	0.13	49
Analysis – given or select	6	12	14	9	8	–0.04	49
Enjoyment – given or select	4	6	24	7	8	0.21	49
Learning – given or select	4	12	18	8	7	0.00	49
Ease of conducting – given or select	8	19	14	5	3	–0.55	49
Summary of 3 delegation of control variables	5	10	21	8	5	–	49
Summary of overall perception (6 variables)	5	12	20	7	5	–	49

–2 = strong preference for prescribed laboratory; + 2 = strong preference for delegated control of laboratory.

measures combined the three factors covering delegation of control over objectives, procedure and analysis. There were 15 students who favoured the controlled approach while only 13 favoured freedom to decide, with the balance being neutral. The overall impression of the experience was computed by summing and rescaling all 6 responses. It shows that somewhat more students, at least as gauged by this measure, favoured prescribed laboratories. This was clearly affected by the relatively strong indication that the students found this type of laboratory more difficult to perform than conventional experiments.

It was thought that the orientation of a given student might be dependent on the course for which they had enrolled. Those enrolling on some courses were likely to have studied technological subjects to a higher level. It is possible that their perceptions of their future professional role might dispose them more or less strongly to an investigative approach.

Sample sizes are rather too small to provide more than tentative support for this conclusion. The Design for Industry class included the highest proportion of students with low-level physics qualifications. Clearly they tended to prefer prescribed laboratories. CNMD and AI&R students all had at least Scottish Higher Physics. It cannot however be said that a clear preference for delegated control can be detected in their combined classes.

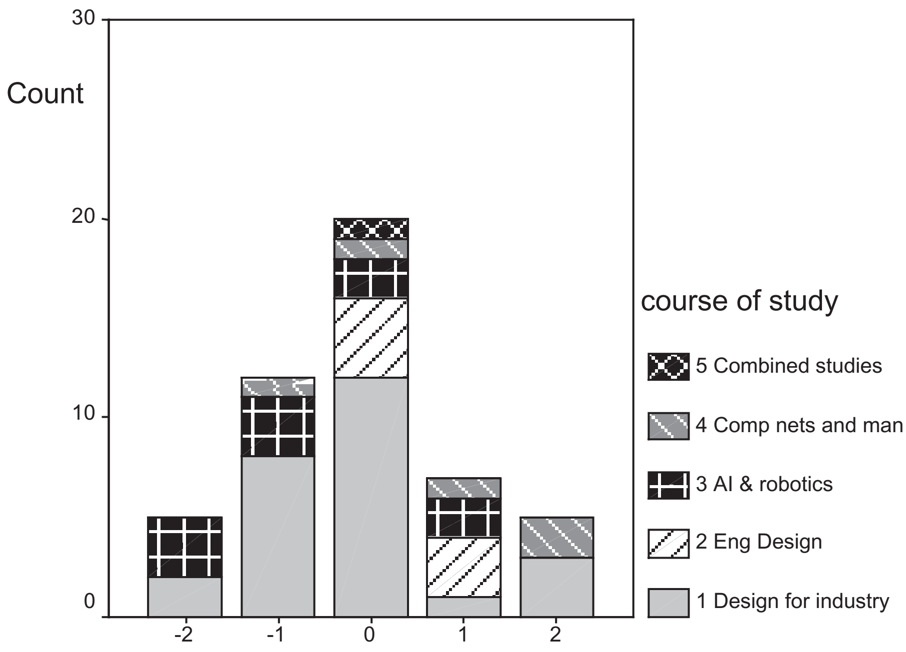

Fig. 2 *Average of scores on all categories of perception of the experience.*

TABLE 2 *Activity sampling of group activity by staff facilitators*

	Discussion of approach	Making/recording observations	Discussing/ analysing results	Unrelated topics
Facilitator A	15	40	30	15
Facilitator B	12	43	35	10
Facilitator C	16	37	41	6
Average	**14.3**	**40**	**35.3**	**10.3**

Staff perceptions

As noted above, five members of staff were present. They were briefed both on the nature of the activity and on their role as facilitators. They were also asked to assess by activity sampling the activities of the groups. None of them recorded their observations in writing and so Table 2 is based on their recollections. Staff were also interviewed subsequent to the laboratory session in free form interviews.

Staff perceptions of the activity are discussed in more detail below. Table 2 shows that they found that most of the discussion among the groups was related to the task in hand. They reported that this had been quite intense with students arguing through alternative methodologies and debating how observations should be interpreted. They concluded that the students were both motivated and applying their prior knowledge constructively.

Discussion

It is immediately obvious that the students' reactions were not as universally enthusiastic as the facilitators thought. Indeed, on more than half of the indices there were more students who preferred conventional laboratories. There could be several reasons for this and we will discuss them below. The first and most important may be in our design of the activity. For example, there may be advantage in a more intensive pre-lab briefing especially when the relatively short duration of the session is considered. Next academic year we will ask the groups to devise their objectives, experimental procedure and safety assessment a week in advance. This should allow much more opportunity for discussion of the merits of possible approaches. Concluding this activity with a plenary discussion will, we hope, help to consolidate the preparation and the students will thus commence the laboratory practical without the uncertainty they had this year.

Laboratory work has been found to be superior to lectures and tutorials in teaching manual skills, providing an understanding of equipment and developing the skills of scientific inquiry.[3] This of course begs the question of whether yet better methods could be devised. Animated videos and multimedia could illustrate what is happening within a working device or during a transformation process. Laboratories were also found to be more flexible in catering for different learning types.

Laboratories were not found to be particularly effective in communicating factual knowledge. Indeed, Johnstone maintains that 'laboratory manuals of the kind used in undergraduate teaching may positively militate against useful learning'.[4] Many laboratory programmes are poorly integrated with other teaching. Johnstone further reports[5] how the use of pre- and post-lab discussions, practices found to be rare by Guy,[6] can consolidate learning. Edward has found that well integrated laboratories can provide concrete applications and visual mnemonics which enhance understanding and recall of related theory.[7] Several surveys have found little evidence that experimental work achieves its stated objectives.[8] This suggests that we must seek convergence between intention and outcome by adjusting either or both of our objectives or our methodologies.

That laboratory work can enhance manual skills is unsurprising but Howe[9] and Holt[10] found that these are quickly lost unless sufficient practice is given to reinforce them. This can be logistically difficult in engineering where equipment is complex and few similarities exist between different apparati. Finegold reported on an effective scheme in which students devised, but did not conduct, experiments to investigate real industrial problems.[11] This concentration on theory and experimental design is unusual. Tamir, however, found that university programmes were dominated by corroboration of theoretical predictions rather than inquiry.[12] In passing, we note that this is the way many students view the exercise. It surely should rather be an exercise to establish the *limitations* of the predictive power of a model.

It is interesting that investigations of approaches to laboratory work in universities have consistently shown that delegation of any level of control to the learner is exceedingly rare. Hegarty conducted a survey of laboratory work in a microbiology course and found that only 3 out of 14 laboratories gave even minimal freedom to students to influence the activity.[13] Tamir had found, using an index she had devised, that the level of enquiry in practicals fell from 1.2 in secondary schools to 0.5 at university.[12] Edward, surveying the approach to engineering laboratories in a Scottish university, found little to suggest that any delegation was involved.[1] It should not be assumed that these 'controlled' approaches are necessarily inferior to more exploratory formats. Meester and Maskill conducted a wide survey of approaches to chemistry practicals and argue the benefits of first-year students learning basic laboratory skills by conducting controlled experiments.[14] It is, however, incumbent on supervisors to ensure that students reflect on these skills. Hunter *et al.* report that 'they (students) have been following recipes so uncritically that they have not learned elementary lessons about accuracy . . .'.[15] Given this need for a sound basis in laboratory practice, it might, however, then be expected that evidence would be found of delegation of control in later years. Work by Guy does not suggest that this progressive development of inquiry skills takes place.[6]

We must at this juncture ask the question: were we wrong to try to introduce delegated control in the first year? Hegarty advocates instruction in laboratory practice rather than having activities primarily designed to teach it. She also advocates instruction in the role of the technologist and the processes of scientific inquiry. This preparation she suggests will permit activities to be designed where the primary aim is the development of skills rather than contextual learning.[13] Our contention was that, by using familiar equipment and by providing intensive support, we could achieve both the development of skills and contextual learning. It is interesting that we subsequently found successful use of a very similar approach in the School of Chemistry at our own university. Hunter *et al.* used common household products as the subject of experiments in which first year students were given only a broad aim and asked to devise methods of investigating them. They found that the students 'find it challenging but also satisfying to take responsibility for their own procedure, and they enjoy the opportunity to work at their own pace'. The supervisors too find that 'the lab sessions are refreshingly unpredictable and enjoyable'.[15]

As we note above, our students' reactions were not as unanimously enthusiastic. A possible influential factor in this variation is prior education. The wide dispersion of prior knowledge of physics has been noted above. We did not ask the respondents to indicate their qualifications and as many chose to remain anonymous we cannot rigorously investigate their importance. Comments suggest that the factor is important. For example, one student said: 'I think more support should be offered instead of relying on group members . . .' Another said: 'due to this being our first technology exercise I had the feeling I was not doing what was expected'. On the other hand one who had Higher Physics said: 'I think it is good to plan it for yourself. It helps me to understand what it all means'.

Some students commented that while it is easier to follow given instructions it is not necessarily better. For example one said: 'the easy option is not always the best' and another said: 'although it is easier to follow given instructions you do learn more when you follow your own ideas'. It seems probable that at least part of the adverse reaction was engendered by concerns about the outcomes being assessed. Quite a number of students commented on this issue. Despite what we perceived as intensive support, several also felt they needed more direct help from staff. As noted above the facilitators deliberately refrained from suggesting solutions, attempting instead to guide the students towards their own solutions. This appears to have left some with anxieties about whether what they decided would be sufficient to gain them satisfactory grades.

Supervisors did not really detect these concerns while conducting the labs. A typical assessment was: "At first they were a bit like well you know 'what-do-we-do sort of thing' but they got into it OK once they got started. Yeah, I thought it went OK. I think they got quite a lot out of it. I thought they were pretty enthusiastic." Another summed up his reaction by saying: 'On the whole though they seemed quite enthusiastic. I think most of them learned something and it was better than the alternative of essays.' A third facilitator thought that the approach had been enthusiastic and constructive. He reported an intense discussion on the implications of observations: 'The heating times for different volumes (in a kettle) get less but they don't go through zero (on a graph).' 'Yeah – that should tell us something! But what?' 'Dunno but something about where the extra heat goes.' Then they noticed the facilitator, asked for and received guidance which allowed them to interpret the results.

Clearly, we must learn from this experience. First we believe that more intensive pre-lab preparation is needed. We intend in the coming session to use the preceding class meeting to allow the students to devise their methodology and carry out their risk analysis. Hopefully if they know that this has been approved before they enter the laboratory their anxieties will be lessened. It will also give us the opportunity to suggest study which might assist them in the intervening week. More careful selection of devices is also called for. We used a fan heater which proved difficult to analyse and a thermo-electric drinks heating/cooling device which, frankly, did not work. Three factors we shall wish to investigate in future applications are prior knowledge, learning style and any apparent correlation of reaction with the specific device being investigated.

Conclusions

We set out to provide the students with a challenging but motivating activity. Because of their lack of experience, and in some cases knowledge, of the subject area, we chose familiar apparatus and provided what we perceived as intensive support. We believed that not only would the students enjoy this more but they would learn more too. If we had evaluated the approach solely on the impressions of the supervisors we would have judged the endeavour to have been successful. The students' responses, however, suggest that at best this was a qualified success and that for some of them it was decidedly unsuccessful. The lessons to be learned are that it is important to solicit student reaction rather than relying solely on staff impressions and that cognisance must be taken of individual student needs and personalities. We still believe that the approach has the potential to enhance learning and we intend to develop our approach to try to address the concerns expressed so cogently by some of our students.

References

1 N. S. Edward, 'The role of laboratory work in engineering education: student & staff perceptions', *Intl. J. Elect. Enging. Educ.*, **39** (2001), 11.
2 D. Clow, 'Teaching, learning and computing', *University Chem. Educ.*, **2** (1998), 58–62.
3 G. C. Bates, 'The role of the laboratory in secondary school science programs', in M. B. Rowe (ed.), *What Research Says to the Science Teacher*, Vol 1 (National Science Teachers' Association, Washington DC, 1978).
4 A. H. Johnstone, 'Chemical education research: facts, findings and consequences', *Chemical Society Review*, **2** (1980), 365–390.
5 A. H. Johnstone, 'Chemistry teaching: science or alchemy?', *J. Chemistry Educ.*, **74** (1997), 262–268.
6 J. J. Guy, *Quantitative classroom observation illustrated by a study of chemistry classroom teaching*, Chemical Education Research Symposium Report, Birmingham (Royal Society of Chemistry, London, 1982).
7 N. S. Edward, *Engineering laboratory practices in higher education: a survey and the development of an alternative simulation of one experiment*, unpublished MEd dissertation, 1995.
8 A. H. Johnstone and M. McCallum, 'Objectives in practical work', in *Proc. Education Division of the Chemical Society*, Nottingham, 1972.
9 M. J. A. Howe, 'Using cognitive psychology to help students to learn', in S*tudent Learning* (SRHE and OU Press, Milton Keynes, 1987).

10 C. E. Holt, P. Abramoff, J. V. Wilcox Jnr and D. L. Abell, 'Investigative laboratory programmes in biology', *Biological Science,* **19** (1969), 1104–1107.
11 L. Finegold and C. L. Hartley, 'An experiment on experiments in a senior laboratory', *Am. J. Physics,* **40** (1972), 28–31.
12 P. Tamir, An enquiry orientated laboratory examination, *Journal of Educational Measurement*, **11** (1977), 43–48.
13 E. H. Hegarty, 'Practical curriculum development; scientific inquiry in university classes', *Research and Development in Higher Education,* **2** (1979),133–142.
14 M. A. M. Meester and R. Maskill, 'The practical side of chemistry', *Educational Chemistry*, **31** (1993), 156–159.
15 C. Hunter, S. Wardell and H. Wilkins, 'Introducing first year students to some skills of investigatory laboratory work', *University Chem. Educ.,* **4** (2000), 12–15.