LABORATORY PROJECTS

Should Students Do Them or Design Them?

Anton P. J. Middelberg
University of Adelaide • Adelaide SA 5005, Australia

Laboratory exercises are an integral part of any chemical engineering curriculum. They perform several crucial roles, including[1] illustrating and reinforcing chemical engineering theory and principles, providing hands-on experience with commonly used process equipment, and demonstrating experimental methodology and techniques. But laboratory projects organized along strict traditional lines have some distinct disadvantages, which can include minimal training in the communication aspects of reporting laboratory results and the possibility of reports being passed down from a group finishing the course to an incoming group.

The communication problem has been widely recognized, and steps are being taken in most engineering courses to address it.[2] The second problem, however, is more serious. One aim of an engineering course is to foster the development of higher-level skills (*e.g.*, analysis and synthesis), but the passing of reports between groups allows students to complete projects without acquiring such skills; the requirement for independent thought and problem solving is conveniently circumvented. While this allows time for a more rigorous study of the traditional lecture-based material, the understanding that would be obtained through careful study of the associated practical work is lost. The high cost associated with changing laboratory apparatus makes it impractical to overcome this problem by altering the available projects.

These problems were identified as existing in the practical component of the Level-3 chemical engineering course at the University of Adelaide. Typically, at the start of the academic year the students were given a series of practical scripts and a handout listing the desirable sections that should be included in a technical report, with the likely content of each of those sections explained. The students were required to undertake a total of twelve projects over the academic year, with each project requiring six hours of laboratory work and approximately twenty hours of data analysis, calculations, and report writing. They worked in pairs and each of them had to submit a total of six reports, which were graded and returned to the student with comments and corrections. While assessment was based solely on the submitted reports, comments generally focused only on technical aspects of the project. The grading system did not reflect the importance which employers attach to communication skills.[3]

Anton Middelberg *received both his BE and PhD degrees from Adelaide University, where he is currently a Lecturer and the Bioprocess Facility Manager. His expertise and industrial experience include the design, modeling, and optimization of biochemical processes, particularly involving the production and recovery of recombinant proteins from* Escherichia coli.

Because of the decline in resources available to Australian engineering departments in the past few years,[4] it has been impossible to update expensive laboratory equipment. Reports of previous-year projects are readily available to students, and there is evidence that results, calculations, and in some instances text, are copied from those earlier reports. While software exists that can compare files for similarities and which could therefore detect such duplication, it is not entirely useful in this case since the reports are rendered in hard copy rather than on disk. Also, such software is not suited to detecting copied results and is unable to ascertain whether calculations were conducted independently or by using sample calculations from previous reports as a template.

To address the above problems, I initiated a series of major changes to the Level-3 laboratory course. The nature of those changes, and the results, are the topic of this paper.

MODIFIED COURSE STRUCTURE

The new course structure consists of three assessable components:

1. *Laboratory project work and reports (70% of the overall grade)*
2. *Report writing and data analysis workshops (15% of the overall grade)*

The students were required to undertake a total of twelve projects over the academic year, with each project requiring six hours of laboratory work and approximately twenty hours of data analysis, calculations, and report writing. They worked in pairs and each of them had to submit a total of six reports, which were graded and returned to the student with comments and corrections.

3. *Laboratory project design exercise (15% of the overall grade)*

The relative weightings reflect the workload for each component. The entire subject constitutes one-sixth of the Level-3 course and has four times the credit points of the Level-3 design subject. Reducing the total number of projects has allowed for introduction of the new components.

The first component is laboratory based and is similar to the old format, although students now submit nine joint reports and the method for report assessment has been changed. Half of the report grade is now awarded for presentation in order to emphasize its importance. A *pro forma* marksheet is used to grade the reports, with half of the marks being awarded for presentation and the other half for technical content. Initial use of the *pro forma* led to a clustering of report marks, and markers complained that the form did not allow sufficient flexibility. A qualitative category called "General" was therefore introduced to compensate for this weakness. A fraction (10%) of the grading for the first component is based on laboratory performance and covers such aspects as safe behavior, preparation, and experimental technique. The "preparation" component has been central to reducing the reliance of students on laboratory teaching assistants.

The second component examines formal report writing and data analysis, while the third component requires that students undertake a comprehensive design exercise involving communication with technical staff and outside organizations, project planning, and budgeting. In combination, these components address the problems of poor communication and the lack of higher-level skill development. A more detailed discussion of these modifications follows.

REPORT WRITING AND DATA ANALYSIS WORKSHOPS

A series of thirteen workshops that cover various aspects of report writing and data analysis has been introduced. Notes discussing report writing are distributed to the students and are reinforced with both good and bad examples from previous reports. A particularly useful technique is placing earlier students' graphs and reports on overheads and allowing the class to critique them. In this way students understand the need to critically analyze their own work from both a presentation and a technical point of view.

The workshops on data analysis cover such aspects as randomization, linear regression, error analysis, and simple comparative statistical tests. Although students have been exposed to these topics in prior years, the connection to engineering is not always clear to them. The workshops aim to reinforce the students' earlier exposure to statistics through worked examples and the need to solve engineering-related problems. Assessment for this component is based both on "hand-in" problems submitted each week for the data analysis section and on a final data analysis assignment, which is also graded on presentation.

LABORATORY PROJECT DESIGN EXERCISE

One method for overcoming the second problem, that of copying reports, is to force students to adopt a problem-solving approach. A research-type of experiment has been described in the literature[5] in which students are told what needs to be discovered and are then asked to plan a solution; after presenting their plan, the students are required to conduct the necessary experiment (within the constraints of available equipment) and to present their findings.

The third component of the modified course at the University of Adelaide, the laboratory project design exercise, is based on a similar approach. Students are told to

- Select a concept from their chemical engineering course which is appropriate for a Level-3 undergraduate experiment and which does not already exist within the department as a chemical engineering experiment. Existing resource constraints are made clear to the students to ensure that their chosen concepts are suitable.
- Submit a plan outlining the concept and the tasks which will be undertaken in order to submit a satisfactory final report. This plan is examined by the instructor and is either approved or disapproved (in which case there is a request for an alternative concept).
- Design the laboratory project, including equipment specifications and sources, after the concept has been approved.
- Submit a final report detailing the concept and how it can be implemented.

The exact form of the final report is deliberately not specified, but the students are told it must include the following:

- Technical and executive summaries
- An outline of the concept, including background theory
- A full PID diagram of the apparatus
- An experimental script to be handed to students undertaking the project
- A budget, including direct costs and departmental

resources (*e.g.,* the workshop)

- A detailed plan for implementation
- An examination of safety implications

Students are not required to build the apparatus and perform the experiment, unlike the research experiment described earlier. This is a conceptual design exercise. The following resources are made available to assist the students:

- Technical staff to comment on the practicality of the designs, to indicate workshop resource requirements, and to assist students in sourcing key equipment items
- Teaching assistants to comment on theory development and to assist with chemical engineering calculations
- Engineering directories listing equipment suppliers
- Telephone and fax machines

The activities undertaken to complete the exercise make it different from traditional chemical engineering process design exercises elsewhere in our curriculum. First, instead of being given a project by the instructor, students are required to select a concept by themselves; second, they must communicate with a wide range of people including technical staff, outside organizations, and senior engineers (*i.e.,* academics); and finally, they must consider implementation issues, including budgeting, resource constraints, and likely workshop difficulties in equipment construction. While many of these tasks are not included in traditional process design courses, they are performed on a daily basis by practicing engineers. It has been stated that "properly organized projects which allow students to function as engineers and to receive feedback are an excellent teaching method."[6] This end, in addition to fostering communication and higher-level skills, is the aim of the laboratory project design exercise.

RESULTS

Students submitted a range of project designs covering diverse topics in chemical engineering. Some were based on projects previously outlined in this journal (*e.g.,* electrochemical reduction in a monolith reactor) while others were based on students' experiences and interests and a desire to illustrate basic principles with novel apparatus (*e.g.,* a hydraulic ram and the adsorption of colored impurities from raw sugar solutions using activated carbon). Other projects were designed to address perceived deficiencies in the course. For example, one group felt that exposure to standards in the laboratory was inadequate and so designed a project based on the Australian Standard for measuring thermal conductivity. Another group, feeling that the biochemical engineering content in laboratories needed to be increased, designed a protein ultrafiltration experiment.

Most projects were well researched and had a strong theoretical background, although some students simply attempted to modify existing equipment or to investigate concepts suitable for prior levels. Such projects were largely detected at the concept-approval stage, however, and as a result the final projects represented an extremely pleasing cross-section of chemical engineering. Students seemed to enjoy the activity, as was evidenced by the quality of the reports received. Given the resources, several of the projects would be worth implementing.

STUDENT REACTION

We conducted a student evaluation of teaching on the class following completion of the exercise. The results are shown in Table 1. All responses show a higher-than-average agreement with the questions, indicating that students benefited from the design exercise. In particular, students seemed to gain instructional benefit from the workshops with technical and teaching staff (questions 2 and 3). This is supported by additional comments from students who stated that the chance to interact with workshop and technical staff gave them a greater feel for reality and the problems associated with implementing engineering designs. Similar positive feedback was obtained from workshop staff.

Students also believe that the subject allowed them to link various parts of their chemical engineering course (question 1) and increased their ability to think independently and critically (questions 6 and 7). Surprisingly, the lowest response was obtained for the question regarding this approach's benefit relative to a lecture-based course (question 5). The spread of responses is highest for this question, and examination of the raw data shows that only a handful of students shifted from positive to negative responses. Is it possible that these students have a different concept of benefit to our own? Have we imposed an artificial concept of benefit on some students by having a predominantly lecture-based curricu-

TABLE 1
Results of Student Evaluation of Teaching for Laboratory Project Design Exercise
Class size: 27 students • Mean Score: 7=strongly agree, 1=strongly disagree

#	Question Asked	Mean/7	St. Dev
1.	This subject demonstrated links to other subject areas.	6.2	0.8
2.	The workshops were relevant to the aims of the subject.	6.3	0.8
3.	The workshops were valuable for my understanding of the subject.	6.1	1.0
4.	I prefer this style of teaching to a lecture-based approach.	5.8	1.1
5.	I benefited more from this style of teaching than I would have if it were a lecture-based approach.	5.5	1.4
6.	My ability to think critically has been increased.	5.7	1.1
7.	My ability to think independently has been increased	5.8	1.0

lum? I shall not even attempt to answer these questions, but they certainly warrant further investigation.

An "open" question in the evaluation allowed students to provide additional feedback. Only positive and constructive comments were received, some of which were:

- More direction as to what to do is required.
- Implement our practicals—students in coming years should be able to understand them better than we did with the existing ones.
- This course was relevant to what I perceive as the "real engineering world." It makes it worth doing.
- Application of the knowledge and skills developed in lectures for all subjects to date is the best aspect—it gives a better understanding as to what it is really all about.
- Learned where and how to contact people for equipment. Good opportunity to apply theory to a real design.
- Learned how to initiate a design (and an idea) and then implement it on my own. Gave me confidence that I would be able to work in the real world.

STAFF REACTION

Technical staff members were asked to provide written comments on how the exercise might be improved in subsequent years. Specifically, they were asked to comment on organizational problems, on how involvement in the exercise affected their other duties, and on perceived student deficiencies.

All the staff felt that the exercise was useful and should be maintained, particularly since it raised student awareness of practical issues. Many useful comments were received regarding procedural and organizational matters, and they will be incorporated into the course in subsequent years. The time commitment from workshop staff was relatively small (about two hours a week for five weeks) and did not detract from their other duties to any large extent. Most staff felt that more time with the students would be useful.

The following were identified as key student skill deficiencies:

- A lack of practical knowledge and an intuitive "feel" for design parameters (*e.g.*, flowrates and volumes).
- Overreliance on technical staff (*e.g.*, what sort of pump should I use, how big should it be, and how thick should I make the pipe insulation?).
- A desire to cost apparatus down to the smallest item (*i.e.*, an unwillingness to use budget estimates and approximate realistic costs for small items).
- Inexperience in preparing questions to technical staff.
- Inability of students to communicate with outside organizations in an effective manner.

The first three points relate to the students' lack of practical knowledge and an apparent desire to defer chemical engineering questions (*e.g.*, pump sizing by characteristic matching) to someone with greater practical experience when confronted with a real problem instead of a paper exercise. This lack of practical knowledge may also explain the problems associated with the costing exercise. As indicated, some students provided costings to the last cent, despite being told that only key equipment items should be outsourced and other costs approximated using the knowledge of workshop staff. The last two problems relate to poor communication, or a desire to seek information without a properly formed question. Again, the exercise in costing proved problematic, as many students approached outside organizations with incomplete specifications for key equipment items.

DISCUSSION AND FUTURE MODIFICATIONS

Overall, the laboratory project design exercise proved popular with both students and staff. Students developed and used a greater range of skills than with traditional laboratory and design projects and they felt they were undertaking something more closely aligned to the role of a workplace engineer. In the long term, exercises such as this might help reduce the frequency of complaints from graduates that their undergraduate education failed to adequately prepare them for the engineering workforce.

Despite the positive outcome, several areas can be improved. First, both students and workshop staff feel that more time should be made available for consultation. Much of that problem, however, may arise from the quality of communication. Also, upon reflection, I believe many students failed to make efficient use of staff time. Poorly prepared questions often resulted in staff having to interrogate students, rather than the desired case of students interrogating staff! To overcome this problem, an additional stage will be incorporated into the exercise: following concept approval, students will be required to submit their apparatus design and engineering calculations for grading. Workshop staff will only be made available *after* this process is complete. In this way we hope that students will be able to form pertinent questions without deferring the design responsibility to staff. Clearly, initial designs will be modified in the light of feedback from staff.

Second, some students requested more direction. Although the course handouts will be modified in response to feed back, I am loath to increase the level of direction. After all—students function best when challenged, despite their apparent desire to avoid using higher-level skills.

Finally, the problem of outside communication will be addressed by requiring that all outgoing communication be done either by fax (with approval by an academic or teaching assistant prior to transmittal) or by using an approved telephone communication plan. In this way, both the content and appropriateness of the request for information can be monitored.

In addition to the above modifications, another course in the chemical engineering curriculum, "Managing People and

Business" (introduced at the same time as this course modification), will be modified to address some of the concerns arising out of this exercise. Specifically, a series of workshops on project management and communication will be run at the start of this laboratory project design exercise.

CONCLUDING COMMENTS

The modifications introduced in the chemical engineering laboratory subject have been well received. Students have received additional guidance in writing reports and analyzing data and have been required to undertake a laboratory project design exercise. This has necessitated the development and use of a range of skills not required in traditional laboratory and design exercises.

Introducing these modifications has meant a reduction (from twelve to nine) in the number of projects undertaken by each group. But this number reduction has been accompanied by an increase in report quality and the need to submit nine joint-author reports rather than six single-author reports. The possibility of introducing research-type experiments for the remaining laboratory projects, as described elsewhere,[5] will be investigated to further improve the quality of the remaining laboratory time. Such an approach has already been adopted for Level-4 students. A reduction in laboratory time at Level 3 has also led to a net reduction in subject resource requirements. The savings are being employed to offset the cost of improving existing experimental rigs (*e.g.,* by replacing chart recorders with data loggers).

The laboratory design project exercise has been particularly useful in fostering development of higher-level skills and reducing the reliance on reports handed down from previous years. Clearly, it will be necessary to restrict the choice of possible designs in future years to prevent copying. Although it would be possible to hand out a list of concepts, I feel it is more useful to allow students to develop their own concept and then disallow it if it is too similar to a previous concept. To this end I am retaining copies of the initial concepts submitted by students (2-3 pages). Given their brevity and diversity, future concept submissions can be easily compared to these filed copies at the concept-approval stage. This is sufficiently early in the exercise to identify possible plagiarists and invite them to submit a new proposal.

Finally, an answer to the question posed in the title of this article. I firmly believe that traditional laboratory courses are an integral part of any curriculum and cannot be dispensed with. But they do have some shortcomings that can be partly overcome by providing formal communication training and by giving students a real engineering problem in addition to laboratory work—design it, don't just do it!

ACKNOWLEDGMENTS

I would like to thank all staff who took part in this exercise for their valuable input and comments. I would also like to thank the Department of Chemical Engineering at the University of Adelaide, and in particular Professor John Agnew, for encouraging innovative approaches to teaching.

REFERENCES

1. Jones, W.E., "Basic Chemical Engineering Experiments," *Chem. Eng. Ed.,* **27**(1), 53 (1993)
2. Pettit, K.R., and R.C. Alkire, "Integrating Communication Training into Laboratory and Design Courses," *Chem. Eng. Ed.,* **27**(3), 188 (1993)
3. National Board of Employment, Education, and Training (Australia), "Skills Sought by Employers of Graduates," Commissioned Report No. 20, December (1992)
4. Department of Employment, Education, and Training (Australia), *Review of the Discipline of Engineering: Vol. 1. Report and Recommendations,* Australian Government Publishing Service, Canberra (1988)
5. Macias-Machin, A., G. Zhang, and O. Levenspiel, "The Unstructured Student-Designed Research Type of Laboratory Experiment," *Chem. Eng. Ed.,* **24**(2), 78 (1990)
6. Wankat, P.C., "Learning Through Doing," *Chem. Eng. Ed.,* **27**(4), 208 (1993) ❐

REVIEW: Hygiene and Toxicology

Continued from page 17.

- Organic phosphates
- Alkane materials
- Phosphorous, selenium, tellurium, and sulfur
- Silicon and silicates, including asbestos

A considerable amount of information on toxicology is detailed in part A of this series. Chapters 2 and 3 should be required reading for not only those who will be involved in the manufacture of any type of chemical but also for all who will be using chemicals in one way or another during their daily life. These chapters outline the care that should be exercised and the risks that could be encountered with various chemicals that have some toxic tendencies.

The usefulness of the twelve chapters dealing with various chemicals identified as toxins varies to a certain degree. Evidently there were no fixed rules provided by the editor to the authors of the various chapters. Thus, a number of presentations begin with an overall consideration of toxicity for the chemicals being reviewed, while other presentations begin with an analysis of specific chemicals and their toxicity properties. Some authors provide a tabular presentation of the physical and chemical properties of all the chemicals covered in the chapter. Other authors do this separately, requiring the reader to go through the chapter to make comparison of the properties. The former approach is more satisfactory since a comparison of the properties could give some guide to the increasing or decreasing toxicity level in a chemical family. Some authors provided more uniform details on the toxicity studies of the chemicals reviewed, while others summarized these all under the topic of physiological responses.

The attention to details was overdone in the chapter on acetone where details were included from the 535 references quoted through 1991. On the other hand, the chapter on alkaline materials appears to require a further update since the most recent reference of the 89