QUALITY IN TEACHING LABORATORIES

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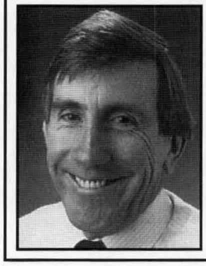
In today's world, increasing attention is being focused on quality in higher education, including chemical engineering. The mission statement of a chemical engineering school could well be defined as: "The mission of the school is to serve the needs of the country by providing first-class teaching and research of the highest quality within the disciplines of chemical engineering and industrial chemistry."

The statement refers to "first-class teaching" and to "research of the highest quality." But, how can we demonstrate the quality of teaching and research?

The Australian Federal Government has recently changed its funding model for universities, providing some central funds for competitive distribution on the basis of quality. With the advent of the associated quality surveys and the provision of quality money, it is no longer acceptable to simply "know" or "assert" that our teaching and research are of the highest quality—we *must provide concrete evidence of that quality.* This paper presents our approach to the problem and provides one answer to the question posed above as it concerns teaching laboratories.

We believe the quality of our teaching is high, based on informal feedback from industry employers on the standard of graduates from our school. Although the quality of our teaching laboratories is likewise high, we believe there must be room for improvement in the quality of these laboratories. We have chosen to focus initially on the laboratories to develop the methods and a system for quality improvement, which we plan to later extend to other aspects of teaching.



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***With the advent of the associated quality surveys and the provision of quality money, it is no longer acceptable to simply "know" or "assert" that our teaching and research are of the highest quality—we* must provide concrete evidence of that quality.**

The objectives of the teaching laboratories must be defined carefully in order to formulate quality measures that accurately reflect performance in achieving these objectives. Only then can the effectiveness of actions taken to improve the quality be assessed. If the objectives are not specified correctly, we will chase the wrong measures. The process of quality improvement thus involves definition of objectives, measurement of present quality standing, identification of improvements, introduction of improvements, and measurement of the resulting quality.

This paper describes our approach to the problem of measuring the quality of existing teaching laboratories. With the large number (sixteen) of laboratory courses taught in our School of Chemical Engineering and Industrial Chemistry and the diversity of the individual experiments in each of those laboratory courses, a common methodology for quality measurement was sought. It should be noted that this is not the comprehensive approach of TQM, inasmuch as it does not focus intensely on the broad interrelationship between the laboratory and the relevant lecture course(s) or on the specific objectives of each individual experiment. Such intense focus would make the development of a common approach difficult, if not impossible, and has been deferred to the stages of identification and introduction of improvements.

OBJECTIVES OF TEACHING LABORATORIES

The overall objectives of our teaching laboratories have been defined for the student:

- ►*To develop skills in the acquisition and analysis of engineering data*
- ►*To develop the ability to communicate experimental findings in written and oral form*
- ►*To reinforce in a practical way theoretical concepts taught in lectures*

In addition to these overall objectives, each experiment has its own specific objectives which should be spelled out for the benefit of all personnel concerned.

QUALITY OF TEACHING LABORATORIES

Definition of quality • What is meant by quality? Quality seems to be a nebulous concept that is difficult to define in an academic context, particularly when it is viewed narrowly in terms of statistical quality control. But Deming's approach[1] to quality improvement offers a way to overcome this difficulty. His approach has been applied and developed in Japan, where it is included as part of KAIZEN.[2] A complete contrast exists between the traditional Western results-oriented approach and the process-oriented approach advocated by Deming and embraced by KAIZEN.

Results-Oriented Approach • In a results-oriented quality control system, products are inspected at the end of the process and accepted or rejected on the basis of measurements made during this inspection. Such measurements are termed R(esult)-criteria and are widely used as part of the Western management style. While this approach ensures that poor-quality products are not sent out of the factory, it does nothing to improve the quality of products produced by the process.

At the University of New South Wales, two types of student survey are used to provide such R-criteria—one for subject evaluation and one for teacher evaluation. Within each survey, there are a number of standard questions and a bank of optional questions, with those relevant to laboratory subjects and laboratory teaching being given in Table 1. From comparison between these questions and the general objectives of the teaching laboratories given above, it is apparent that the surveys provide more of a customer-satisfaction rating than an assessment of how well the overall and specific objectives of the teaching laboratory were met. Additional questions, specifically related to the achievement of

TABLE 1
Student-Survey Questions

Subject Evaluation Questions

Standard questions
(Each question rated on a 1-7 point scale, with 0 points if not relevant.)

1. How well have the objectives of the subject been made clear?
2. To what extent was there agreement between the documented objectives of the subject and what was actually taught?
3. Does the weight given to the assessments so far reflect the importance of the topics assessed?
4. How adequate has been the feedback on your progress?
5. How well coordinated were the various components of this subject? *e.g.,* lectures, tutorials, assignments, laboratory work
6. How appropriate have been the assessment tasks in the subject?
7. How adequate have been the physical facilities (rooms, laboratories, etc.)?
8. How helpful were the tutorials and seminars?
9. How helpful were the demonstrations/laboratory sessions/field trips, etc.?
10. How adequate were the support structures within the subject? *e.g.,* counseling, advice, and help with problems
11. How well structured were the materials in this subject?
12. Overall, how useful were the texts and/or supplementary materials?
13. Overall, how useful were the reference materials?
14. How would you rate the overall quality of the teaching in this subject?
15. How appropriate was the difficulty level of the subject compared with other subjects?
16. To what extent would you recommend that another student, like yourself, study this subject?

Teacher Evaluation Questions Specifically on Laboratory Teaching

Optional questions
(Each question rated on a 1-6 point scale, with an additional option of not applicable.)

801. Sufficient time has been given to complete work in these laboratory classes.
802. There has been a clear and supportive relationship between these laboratory classes and the lectures.
803. There has been adequate access to equipment needed to complete assignments during these laboratory classes.
804. I have been encouraged to work independently in these laboratory classes.
805. Clear and concise instructions have been given in these laboratory classes.
806 Marker's comments and criticisms on assessable work have been helpful in these laboratory classes.
807. Laboratory assignments were reasonable in length and complexity.
808. Equipment, materials, etc., have been reliable and in working order in these laboratory classes.
809. The instructor ensured that purposes and procedures of practical exercises were understood by students during these laboratory classes.

these objectives, need to be formulated. The subject evaluation survey allows for the inclusion of up to nine such questions.

KAIZEN's Process-Oriented Approach[2] • KAIZEN is an umbrella concept covering the Japanese practices that have recently achieved such worldwide fame. A KAIZEN strategy maintains and improves the working standard through small, gradual improvements, whereas innovation provides radical improvements as a result of large investments in technology and/or equipment. Both KAIZEN and innovation are necessary to maintain a competitive advantage, and the emphasis placed on innovation by the traditional Western management style has led to neglect of the opportunities for continual improvement of existing systems. KAIZEN is synonymous with continuing improvement involving everyone—managers and workers alike.

Another important aspect of KAIZEN has been the emphasis on process. KAIZEN is a process-oriented way of thinking and a management system that supports and acknowledges people's process-oriented efforts for improvement. This is in sharp contrast to the Western management practice of reviewing people's performance strictly on the basis of results and not rewarding the effort made. "Building quality into the process" is the KAIZEN philosophy, thus ensuring that quality products result.

The process-oriented approach analyzes all of the individual steps in the overall process and provides measurements which indicate the quality of the individual process steps. These measurements are termed P(rocess)-criteria and provide concrete ways for gradually improving the quality of each step in the process, in contrast with the R-criteria, which only measure the quality of the final product.

PROCESS MODEL FOR A LABORATORY EXPERIMENT

During initial discussions, it was commonly assumed that the "student mark" was an indication of the quality of the teaching experiment, although many academics were unhappy with this as a quality measure because the student's assessment should reflect the performance of the student rather than the quality of the laboratory. Therefore, we sought an approach to quality measurement that allowed separation of student assessment from measurement of the quality of the teaching laboratories.

We chose a process-oriented approach toward improving the quality of each experiment in each laboratory. A single laboratory experiment can be depicted as a "process," as shown in Figure 1. The process steps have been separated into those performed by the students doing the experiment and those for which academic staff and technical support staff are responsible. The quality of the students' process steps depends on the ability and effort of the students and is reflected in their mark achieved for the experiment. As academics, we have no direct control over the quality of the student's process steps—hence the difficulty in defining quality.

We do control the process steps for the academic and technical staff, however. The KAIZEN approach of continually improving these steps in the process will improve the quality of the overall process. Measurement of the quality based on this process model then requires the definition of quality measures for those steps under the direct control of academic and technical support staff.

QUALITY MEASUREMENT OF TEACHING LABORATORIES

An initial in-house survey of staff to identify quality measures for the teaching laboratories provided a wide range of responses, many of which measured efficiency or cost rather

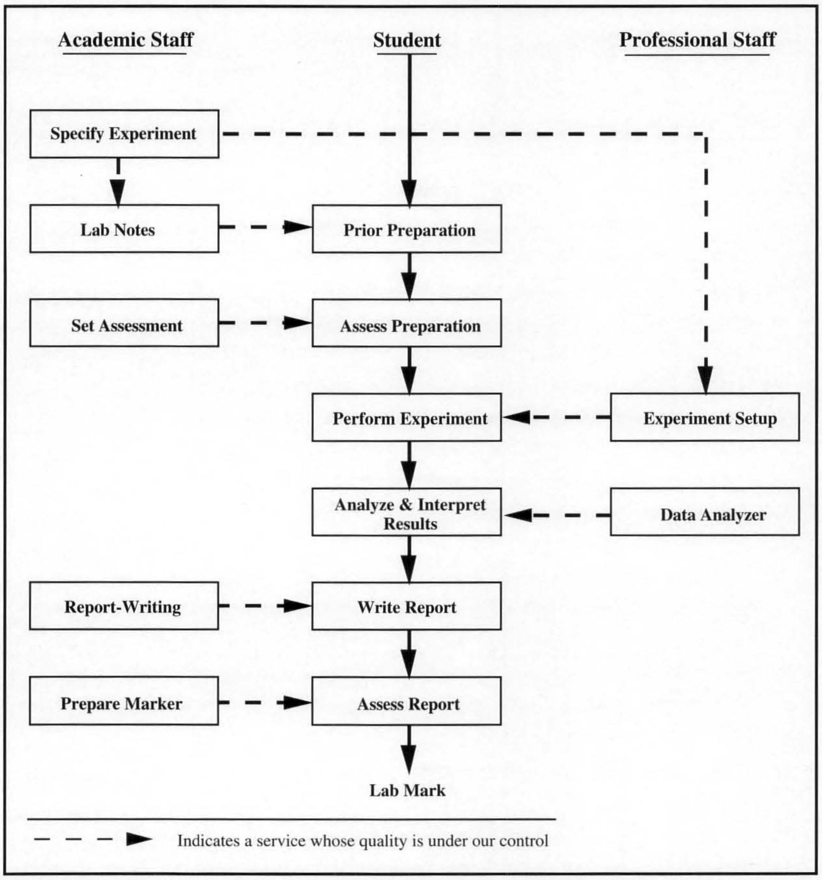

Figure 1. *"Process" flow-sheet for a typical laboratory experiment, showing the process steps for which academic staff, students, and professional/technical support staff are responsible.*

than quality! Cost and quality are different objectives, as observed by the president of the IChemE, who noted, "The driving down of unit cost is damaging the quality of engineering, and chemical engineering in particular, in universities."[3] This idea that improved quality and lower cost are conflicting objectives is directly challenged by KAIZEN's long-term philosophy of continual improvement, leading ultimately to both improvement in quality and lower cost. The confusion of the issues of quality and cost highlights the difficulty of defining quality and has led us to adopt KAIZEN's process-oriented approach which neatly sidesteps this difficulty.

We have identified a series of P-criteria **Quality Measures** appropriate to each of the process steps in Figure 1 under our control. These measures are fairly universal for all our teaching laboratories, even though the specific objectives of the individual laboratories and individual experiments differ. These measures have been assembled into the quality measurement survey given in Figure 2, which has been slightly modified to be more applicable for the computing and pilot plant laboratories only. Note that report-writing, although a major objective, is a student process step and is not covered by this form. Each tick in a box in Figure 2 counts as 1, and an overall quality index for the experiment is calculated according to the formula at the bottom of the form. The quality index is designed to range from a minimum of -10 to a maximum of +10, with column B ticks counting zero so that the index is non-linear towards both extremes.

The quality index has been calculated for each experiment in each of our laboratory courses to

QUALITY MEASUREMENT
CEIC TEACHING LAB EXPERIMENTS

LABORATORY________________ **Date:**________
EXPERIMENT________________

1. Specify experiment

	0-5 yrs	N/A	>5 yrs
Age of Standard Test used/Calibration of equipment?	☐	☐	☐
	0-5 yrs	5-10 yrs	>10 yrs
Average age of equipment/instrumentation?	☐	☐	☐

2. Lab notes/instructions

	0-5 yrs	5-10 yrs	>10 yrs
Time since last revision by academic?	☐	☐	☐
Comprehensiveness—does it include:	Complete	Incomplete	None
Aim of experiment	☐	☐	☐
Relationship to lecture course(s)	☐	☐	☐
Equipment description	☐	☐	☐
Equipment operating instructions	☐	☐	☐
Data analysis requirements/use of results	☐	☐	☐
Reference data	☐	☐	☐
References	☐	☐	☐
Assessment requirements	☐	☐	☐

3. Assessment of prior preparation

	Yes	N/A	No
Written standardized procedure for prior assessment?	☐	☐	☐
Is the consistency of marks assessed?	☐	☐	☐

4. Marker preparation

	Yes	N/A	No
Are written instructions provided to markers?	☐	☐	☐
Is a model report and marking scheme provided to markers?	☐	☐	☐

5. Experiment setup

	Yes	N/A	No
Is there a written setup procedure for this experiment?	☐	☐	☐
	< 2	2-4	> 4
Number of equipment malfunctions during the lab this year?	☐	☐	☐

6. Report assessment

	Yes	N/A	No
Is the consistency of marks assessed?	☐	☐	☐
Is feedback provided to the students?	☐	☐	☐
	< 1 wk	1-2 wks	> 2 wks
Turnaround time for feedback to the students?	☐	☐	☐

TOTALS (sum of number of ticks in each column): **A=**☐ **B=**☐ **C=**☐

QUALITY INDEX = (A - C)/2 = ☐

Figure 2. *Quality measurement form for teaching laboratory experiments, including the definition of the quality index.*

Laboratory	# of expmts	hrs/ exprmt	Av. Quality Index
Polymer Chemistry	5	4	1.6
Chemical Engineering Lab 1	7	3	6.6
Chemical Engineering Lab 2	7	3	5.2
Instrumental Analysis 1	12	3	8.58
Instrumental Analysis 2	3	4	8.5
Chemistry of Physical Processes	12	2	9.17
Environmental	3	3	9.33
Fuel Analysis	8	3	-0.4
Fuel Plant	6	12	-1.7
Valve Calibration	2	0.75	-0.5
Pilot Plant	12	3.5	-4
Computing	10	*	2.35
Hydrometallurgy	4	42	4.13
Mineral Engineering Processes	5	4	3.2
Industrial Processes	4	21	-0.5

* unspecified

Figure 3. *Average quality indices for the experiments in each laboratory course.*

provide a baseline measurement of the present quality, with the average results being presented in Figure 3 and ranging from -4 to 9.3. The quality surveys then indicate areas for improvement of each experiment, and academic and professional staff are presently using them to improve the quality of our laboratory courses by targeting those areas highlighted as deficient by this quality measurement. We then plan to apply the same quality measures next year, to assess the effectiveness of the actions taken to improve the quality of the processes in our teaching laboratories.

CONCLUSIONS

This paper has described a KAIZEN process-oriented approach for improving the quality of existing teaching laboratories that provides relevant quality measurements and indicates how the quality could be improved. Use of such P(rocess)-criteria neatly sidesteps the difficulty of defining quality for laboratory experiments and allows separation of student assessment from quality measurement. Efforts made to improve the quality can then be assessed by the improvement not only in these P-criteria but also in the R(esult)-criteria measured by the standard student surveys for subject and teacher evaluation.

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CONCEPTUAL DESIGN PROBLEM

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adsorption. The students were also given at least a flavor of how these different processes are able to compete economically, depending upon differences in the feed specifications and product requirements.

The scope of the actual student reports has varied enormously. Some groups tended to get overly involved in the minutiae of the design calculations (*e.g.,* constructing numerous McCabe-Thiele diagrams at different temperatures and distillate/bottoms compositions for the distillation) while other groups have made very effective use of available approximate methods like the Fenske and Gilliland equations. Some groups have actually tried to integrate heat exchangers into several of the processes in order to reduce the overall energy costs. And many of the groups have examined the behavior of several hybrid processes for the CO_2-CH_4 separation, *e.g.,* using a combined membrane and distillation system to obtain high purity CO_2 and CH_4 products at a significantly reduced overall cost.

Although it is always difficult to judge student response to an assignment of this nature, my impression is that the students have found this project to be a very positive addition to the mass transfer operations course and to the overall coverage of engineering design. Almost all of the students have appreciated the "reality" of the project and the enormous range of possibilities that they were able to explore. I think they have also been fascinated by the different answers obtained by the individual groups arising simply from the differences in the feed characteristics (often coupled with differences in the design strategies used by the different groups).

Some of the students have been frustrated by what they viewed as a lack of "structure" for the project. While these students often had a great deal of difficulty developing an effective approach to the design analysis, even they seemed to develop a much better appreciation for the underlying principles of engineering design and of the critical importance of developing an effective strategy for attacking this type of open-ended design problem (instead of simply using the type of brute-force approach that generally works so well for most standard chemical engineering homework problems).

Overall, I feel that this project has had an extremely positive impact on the teaching of mass transfer operations, and I can strongly recommend using this type of conceptual design analysis in similar classes at other universities.

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