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An Integrated Foundation Course in Chemical Engineering*

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This paper presents the development of an integrated foundation course in chemical engineering, which was specifically designed to meet the needs of a class of students from widely differing educational backgrounds. The following premises formed the basis for the course: (a) it should address the needs of disadvantaged students as well as advantaged students; (b) The Chemical Process Industries and Computation courses should be integrated with the conventional mass and energy balance subject matter; (c) the course should progress towards the application of computer flowsheeting packages. The detailed implementation of the course is described, including course objectives and a course outline.

INTRODUCTION

THIS paper describes the development of a foundation course in chemical engineering which integrated the Chemical Process Industries and Computation courses with the normal subject matter of such a course, namely mass and energy balancing. This course was designed to meet the needs of a population of students from widely disparate educational backgrounds. It had to help those from severely disadvantaged backgrounds at the same time as challenging the top students.

In addition, the course was meant to be a filter, in that students unlikely to succeed in later years were to be discouraged from continuing to study chemical engineering, as well as forming a foundation for all the chemical engineering courses which follow.

BACKGROUND

The chemical engineering degree at the University of Cape Town is a four year programme, with the first year being largely basic sciences, the second year contains further courses in chemistry and mathematics together with introductory chemical engineering, the third year involves intermediate chemical engineering, and the fourth year advanced chemical engineering.

For many years, the second year introduction to chemical engineering consisted of a 4-credit course in Chemical Engineering Calculations (mass and energy balancing) in the first semester, followed by 2-credit courses in Fluid Flow and Heat Transfer in the second semester.

Then in 1984 the department decided to rationalise course structures and offer larger, more integrated courses in the various subject areas. As a result of this, Fluid Flow and Heat Transfer were combined with Transport Phenomena and moved into the third year, and Chemical Engineering Calculations was combined with Computation and Chemical Process Industries and expanded into a course lasting the whole year, called Chemical Process Analysis (CPA).

At the same time, there was concern over students who were entering many third year courses with an inadequate grasp of the fundamentals taught in second year. It was therefore decided to make CPA a prerequisite for all third year chemical engineering courses, and to ensure that students passing it had mastered the basics.

The creation of the CPA course coincided with the start of a large increase in the proportion of students from disadvantaged backgrounds entering chemical engineering. This is reflected in the enrolment for CPA which is shown in Fig. 1. It is also clear from Fig. 1 that the absolute size of the CPA class was increasing at the same time. Since 1987, about 40 per cent of the students in CPA have been disadvantaged to a greater or lesser extent (see Fig. 2). In Figs 1 and 2, students have been classified by racial background, because the school education system has been classified this way. The group labelled 'Other' comprises largely Coloured students, with some Indians as well.

The first CPA course was run in 1985. It consisted of basic mass and energy balancing, taught out of Himmelblau [1] (as for the previous Chemical Engineering Calculations course), plus computation, chemical process industries and some unit operations.

I was asked to take over CPA in 1986, together with Professor J.-P. Franzidis. I felt that the unit operations material was out of place in the course and decided to include process synthesis and flowsheeting instead, as extensions of basic mass and energy balancing, in order to make the course hang together better. During 1986 we reviewed the

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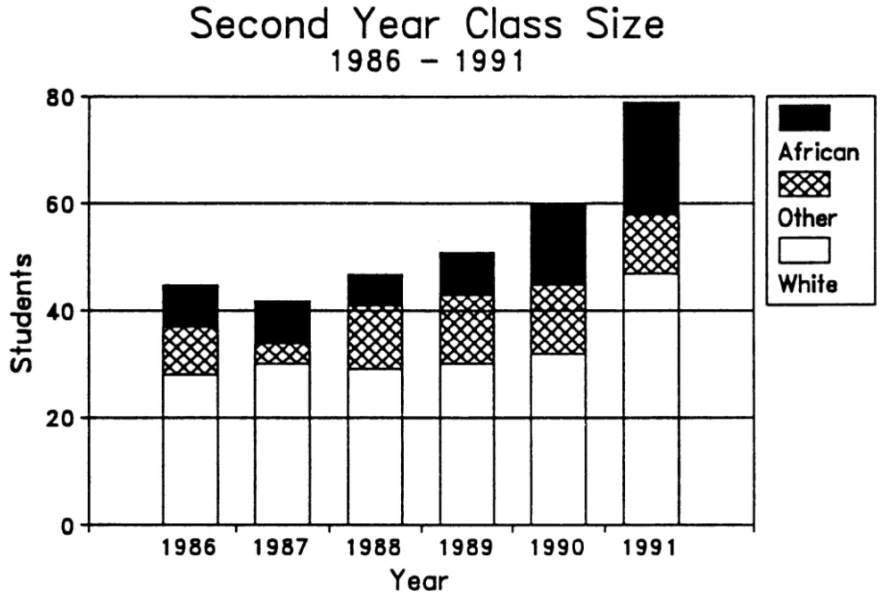

Fig. 1. CPA class size.

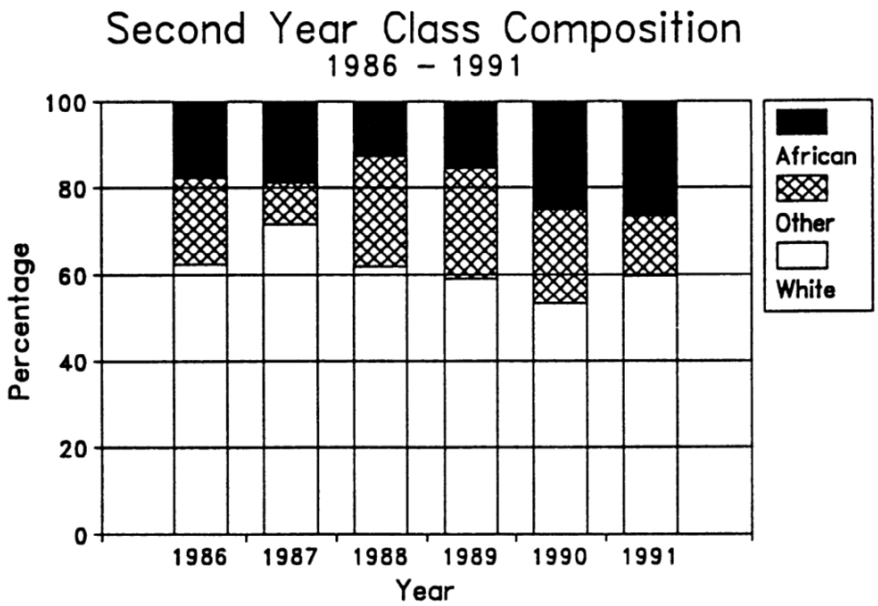

Fig. 2. CPA class composition.

content of CPA as well as the textbook used to teach it. The course presented here was a result of that restructuring and the development which followed.

GUIDING PRINCIPLES

The following principles guided us in the restructuring of the CPA course:

The course should meet the needs of the struggling disadvantaged students as well as stretch the bright advantaged students.

These seem to be two mutually exclusive demands. We had already experienced the difficulty of teaching a class in which the ability to cope with the material being presented was enormously widespread. We had observed that one of the difficulties manifested by the disadvantaged students was being unable to cope with a problem because of unfamiliarity with the process involved. This meant that it was important to introduce the student to the processes used in problems before they were asked to solve them.

At the same time we had to be wary of putting off the brightest students by boring them. Thus it was also important to include material which would excite them and stretch their capabilities.

Computation and chemical process industries should be integrated with the rest of the subject matter.

In order to enhance the learning process, both computation and chemical process industries was integrated with the mass and energy balance material. This was particularly important in view of the different nature of the computation material. This could readily be achieved by introducing computation techniques as they were required to solve the mass or energy balance equations which had been derived. A subsidiary objective grew out of this, namely to teach the students which level of computational aid to use in solving any particular problem, such as ordinary calculator, programmable calculator, spreadsheet, own computer program, special computer package.

As far as the chemical process industries material was concerned, the need to introduce processes before solving problems on them has already been noted. Thus it would be best to expose students to certain processes which would then form the basis for subsequent problems.

The course should develop from simple to more complex problems, ending with the application of flowsheeting packages.

It was strongly felt that the course should end with the sophisticated application of flowsheeting packages to the solution of mass and energy balance problems.

In order to achieve this, the course needed to start with simple problems, while ensuring that as it developed, basics were reinforced. This would hopefully meet the needs of both the weak and the strong students. There was a danger of boring the strong students in the early part of the course. However, introduction of some more difficult concepts early on might counter this.

DETAILED OBJECTIVES

In addition to the major guiding principles outlined above, there were a number of subsidiary objectives which we wanted to achieve in the process of this course. A detailed set of objectives is given in Appendix 1 and will now be discussed.

The first five objectives cover the basic material included in the course: objectives 1, 2 and 3 refer to the basic mass and energy balance coverage, and objectives 4 and 5 deal with computation and chemical process industries.

The next two objectives deal with extensions of the basic mass and energy balance material. Objective 6 is an extension of both mass balancing and chemical process industries to elementary process synthesis. Objective 7 refers to the development from simple balances to a systematic analysis of mass and energy balance problems and hence to the use of flowsheeting packages.

The last three objectives cover other aspects of the students' development which form part of the course: objective 8 deals with the ability to communicate technical information using a variety of media, objective 9 deals with the ability to work in a team, and objective 10 deals with the capacity to tackle open-ended problems.

IMPLEMENTATION

In working out the principles and objectives described above, it was decided to start the course with simple mass and energy balances. These would need to be based on particular processes because of the needs of the disadvantaged students, as discussed above. The textbook by Thompson and Ceckler [2] was ideal for this purpose, in that each new section is based on the production of a certain chemical commodity. Thus, the first half of the course was taken directly from the textbook. Another factor in favour of Thompson and Ceckler was the integration of mass and energy balances throughout, rather than first dealing with all mass balancing and then all energy balancing.

In developing the course towards the application of flowsheeting packages, it was felt that the textbook by Reklaitis [3] provided the proper foundation for flowsheeting, with its detailed working of the application of degrees of freedom analysis to mass and energy balance problems. The second half of the course was accordingly based on Reklaitis.

Other textbooks such as Himmelblau [1] and Felder and Rousseau [4], while having many helpful features such as test-yourself questions and answers to selected problems, did not meet the requirements described above for texts for this course. They do, however, provide a valuable backup in the library as additional resources.

In order to give meaning to the computation side of the course, it was integrated into the course where it would be appropriate for solving the problems being handled. The philosophy here was to make the students proficient at the computer language they had been taught in their first year Applied Mathematics course, rather than teach them a new language. The language used at this time was True BASIC, which is a structured form of BASIC, whereas we would have preferred our students to have learnt FORTRAN (which they had done traditionally) or Pascal.

At the same time, they were introduced to the numerical methods required to solve the problems, such as root-finding, curve-fitting and matrix solution of simultaneous equations. Reklaitis [3] also includes some of this material.

The use of spreadsheets was taught using As-easy-as, an excellent package for which the university could obtain a site licence at a reasonable cost. A particular advantage of As-easy-as is its matrix manipulation capabilities. The initial version we had could also fit onto a single 360-kbyte floppy disk, which meant students could readily use it on their own PCs. As-easy-as provided a good introduction to the basic principles of spreadsheeting. In later years our students have had access to Quattro-Pro and they have been able to use it effectively.

As far as the teaching of flowsheeting packages is concerned, we used to introduce the students to PROCESS but found it too time-consuming at this level, because the students not only had to learn the syntax of the input language, but also how to run it on the mainframe computer. With the introduction of the PC-based PRO/II we moved to that, which was much more user-friendly, but had a rather lengthy solution process for simple problems such as those dealt with in this course. The system currenty used is HYSIM which is both easy to learn and quick to supply answers.

The chemical process industries material was covered in a variety of ways. The first was by the processes covered in Thompson and Ceckler. The second was by way of inviting visiting lecturers from industry to talk about their plants. The third was by the students themselves, in groups, preparing a written report on a particular chemical or group of chemicals, and then presenting this to the whole class. Appendix 4 contains a list of topics used in these projects, which reflect the South African chemical and mineral processing industries. The fourth way was by industrial plant visits, to an oil refinery, a fertiliser plant, and a cement factory: these were all timed to coincide with appropriate sections of the course.

Appendix 2 shows a course outline based on what has been presented above. This represents an ideal sequence: in reality the course was never run quite like this, largely because of availability of staff at particular times. Appendix 2 also shows the distribution of the 120 lectures in the course among the different topics, as well as a breakdown of the 40 afternoon sessions which were run.

In this outline, sections 1–4 and 7–12 are dealt with in Thompson and Ceckler, and sections 15–20 in Reklaitis. Sections 5 and 6 deal with the initial computation material, which is also covered less explicitly later on in the course in problem assignments, particularly in section 17.

The communication aspect of the course was met largely through the chemical process industries projects, both written and oral. It was also covered in the design project run at the beginning of the course. The primary objective of the design project was to introduce the students to open-ended problem solving and group work. Further exposure to group work was given in the chemical process industries and process synthesis projects.

DISCUSSION

The course as presented above was the result of a process of development which has continued into the future. Originally there was also coverage of dimensional analysis (which was transferred to a more appopriate course) as well as unsteady balances, initially included because students had commented on what a shock it was to only encounter unsteady conditions for the first time in the control course in their fourth year. It was removed by decision of the staff in the department.

The staff also decided that the process synthesis material was too advanced for a second year course, but it is left in here becuse it is one of the elements which catches the imagination of the brighter students. It also ties in well with the chemical process industries section of the course, in which alternative processing routes are dealt with.

Course assessment has been another area of importance and details are give in Appendix 3, which includes D.P. (Duly Performed) requirements, mark assignment, and project weighting.

The D.P. requirements are conditions set for the students to be able to write the examination, which are meant to ensure that students have had exposure to or mastered non-examinable material. The test average requirement does not fulfil these criteria, but it was included to provide a means of saving students who have had little hope of passing CPA from failing other courses in an attempt to pass this one.

It will be noted that the mark assignment includes 25 per cent for tutorials and projects, which have generally helped to raise students' marks. The first test counts less than the other two because it was found that many students were still at sea when it was given. The placement of the mid-year test was problematical, in that it fell in the mid-year examinatin period together with final examinations for semester courses. A solution was to place it after the mid-year break.

We are currently moving away from these large tests to a series of smaller in-class tests, which provide more rapid feedback to students at more frequent intervals. Another helpful technique has been spot tests, which are both written and marked (by the students themselves) within a lecture period.

One of the difficult areas was how to examine the chemical process industries material. At first we ran a test covering this part of the course in order to encourage attendance at the student lectures, and also marked students on their oral presentations as well as the written submissions. This did not work very well because the quality of the presentations was often inadequate, so it was hard to learn anything from them.

We subsequently made attendance at the lectures compulsory and removed the test. This was also problematical in that the audience was not always receptive. Then our Professional Communication Unit, who provide input to this project on both written and oral communication, pointed out that the students had an impossible task in trying to communicate information to their peers as well as to impress the staff who were assessing them.

As a result we removed the marking of the presentations. At the same time, we widened the scope of the projects and gave them to larger groups, which were in fact the co-operative study groups to be discussed next. This worked very well in most of the eleven groups.

The number of disadvantaged students in this course before the new structure was implemented was too small to make comparisons with the past meaningful. Within this structure, a number of different systems were tried to help these students master the material of the course. There was no marked improvement in their success until a system of collaborative study groups was introduced towards the end of the 1990 academic year.

This system was fully implemented in 1991 and 1992, leading to an average increase in the success of disadvantaged students of 55 per cent, compared with an increase in the success of advantaged students of 16 per cent. This system, which was developed at UCT in conjunction with our students, was based on groups used in Minority Programmes in the U.S.A. Full details of the collaborative study group system may be found in Fraser [5].

OUTCOME

The success of this course may be judged by how the students fared in the later years of study. Those

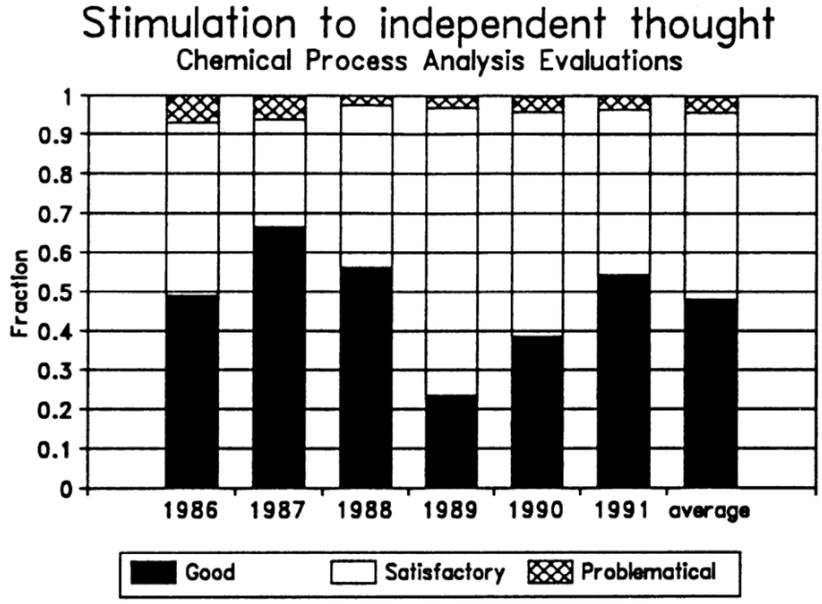

Fig. 3. Student evaluation of degree to which course stimulated them to independent thought.

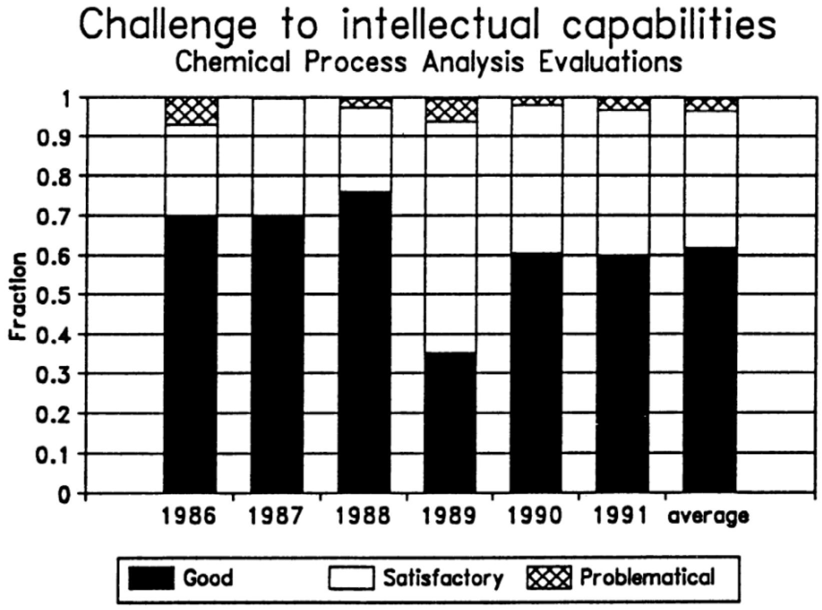

Fig. 4. Student evaluation of intellectual challenge provided by course.

who passed the course invariably graduated, although some took more than a further two years to complete the degree. At the same time we also seem to have eliminated the 'long-service' students who eventually graduated after spending two years over each academic year. One of these students had commented that we had led him on by allowing him to pass early on in his career.

Another important observation was that there was a significant group of students who benefited from the development in the course as it progressed. These students failed their first two class tests, but did well in both the third class test and the final examination. The reinforcement in the second semester clearly helped them. Many of these were disadvantaged students, who went on to complete the degree in the normal time, and some of whom ended up doing higher degrees.

Course evaluations were conducted each year. These also indicated the degree to which the course fulfilled our expectations. Figures 3 to 8 show responses during the period 1986–1991, as well as the average over the period.

When asked about the degree to which the course had stimulated them to independent thought (see Fig. 3), 48 per cent on average thought this was good, 48 per cent said it was satisfactory, and only 4 per cent found it problematical. It is not clear from how the question was framed whether the problems were boredom or inability to be

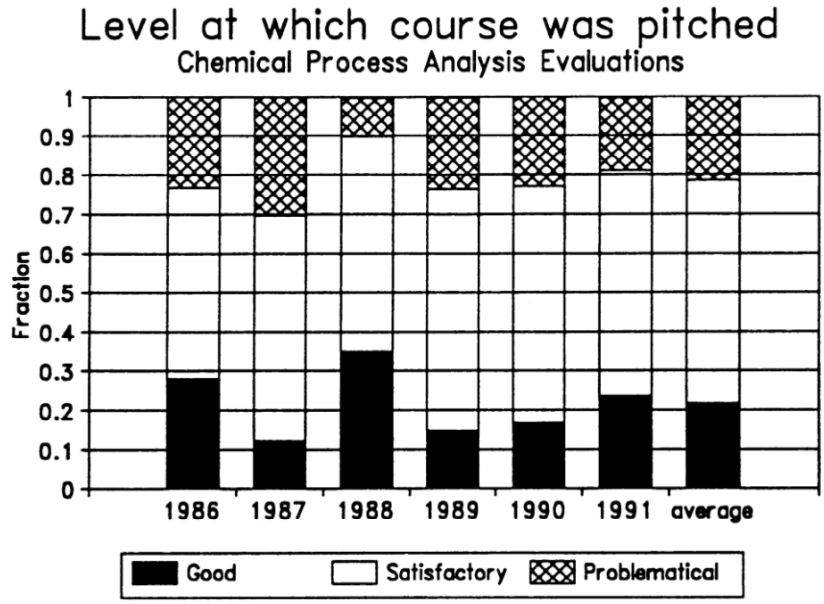

Fig. 5. Student evaluation of level at which course was pitched.

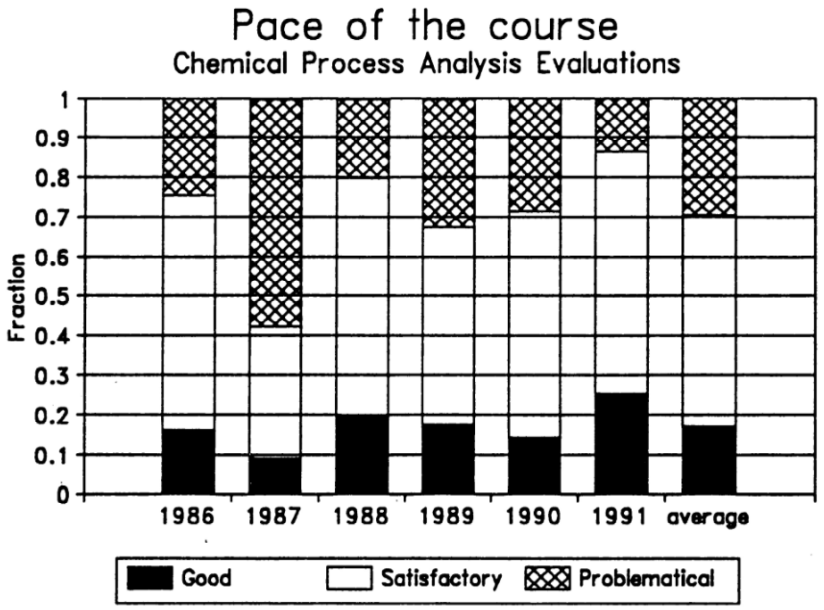

Fig. 6. Student evaluation of pace of course.

stimulated. Regarding the challenge to their intellectual capabilities (Fig. 4), 62% thought it was good and only 3 per cent had difficulties.

In response to the question concerning the level at which the course was pitched (see Fig. 5), 22 per cent thought it was good and 21 per cent indicated they experienced difficulties with it. These responses seem to indicate that the first guiding principle was achieved to a large extent. As far as the pace of the course was concerned (Fig. 6), 17 per cent felt it was good and 29 per cent had difficulties with it. There was a particularly large negative response the first time the course-structure presented here was introduced in 1987. This changed considerably in subsequent years, despite the fact that the course remained virtually the same. There was a significant shift in both the good and problematical responses in 1991 when the course content was reduced by 20 per cent.

The change in textbooks from Himmelblau (1986) to Thompson and Ceckler plus Reklaitis (1987 onwards) was very favourably received (see Fig. 7), especially in 1988, when there were sufficient copies of both books available. The more negative trend after that reflects the three-fold increase in the price of Reklaitis and its consequent lack of accessibility to many of the students.

Finally the collaborative study group system was very well received by the students, even in 1990 when it was only used for four weeks right at the

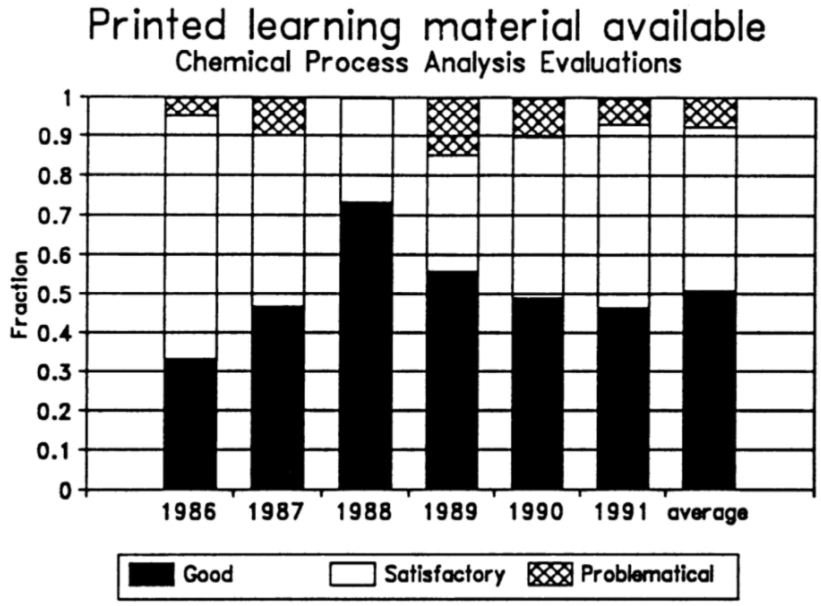

Fig. 7. Student evaluation of textbooks made available to them.

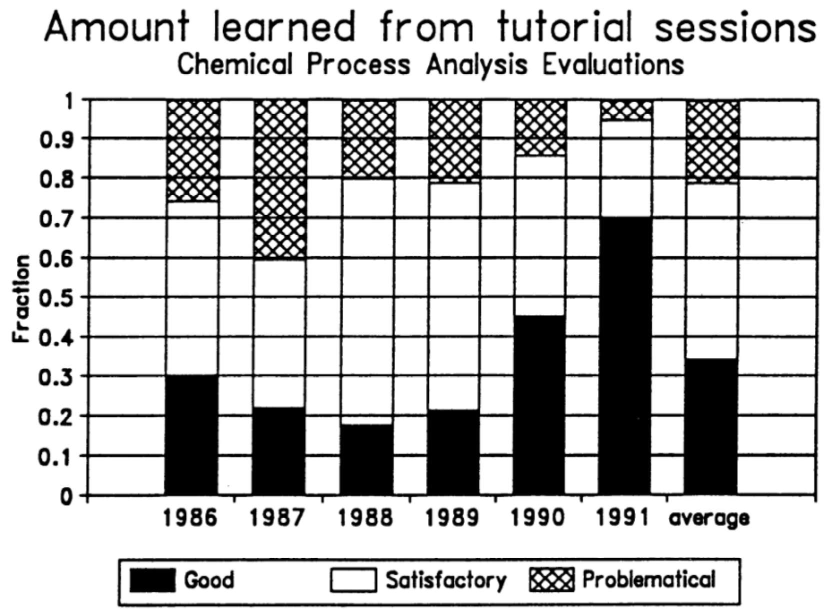

Fig. 8. Student evaluation of tutorial sessions.

end of the course (see Fig. 8). In 1991, when it was implemented fully, 69 per cent felt the tutorial sessions were good and only 5 per cent experienced difficulties with them. These figures should be compared to the average responses in 1988 and 1989 which were 19 per cent positive and 20 per cent negative respectively.

CONCLUSION

As far as can be judged, the Chemical Process Analysis course presented here has met the requirements we set for it, both in terms of meeting the needs of the widely disparate groups of students in it, as well as in terms of providing a filter and foundation for the rest of the chemical engineering curriculum. I trust that others will be able to benefit from our experience in both constructing the course and running it.

Acknowledgements—I wish to thank all my colleagues in the Chemical Engineering Department at UCT for their critical input to this course. I am particularly grateful to those who taught this course with me during its formative period, namely Professor J.-P. Franzidis and Dr Gary Foulds, as well as to Professor Andrew Sass of the ASPECT Programme for introducing me to the idea of collaborative learning.

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APPENDIX 1
COURSE OBJECTIVES

By the end of this course each student should:

1. Understand the units and dimensions used in describing the properties of the materials.
2. Be able to determine the mass and energy flows in typical processes in a chemical plant such as mixing, reaction, heat transfer, phase transition separation, recycle and purge. This will involve the application of reaction stoichiometry, ideal and real gas properties, equilibrium relationships, the first law of thermodynamics, and heats of formation and transition.
3. Know how to estimate the physical properties required for determining mass and energy balances.
4. Be adept at the use of computers in the solution of chemical engineering problems: this will involve competence in True BASIC programming, as well as the ability to use spreadsheets and specialised packages and to choose the appropriate computation tool for solving a particular problem.
5. Have a knowledge of important industrial chemical processes and equipment.
6. Be able to evaluate alternative process routes for production of a particular product.
7. Have developed a systematic approach to the solution of mass and energy balance problems, including the use of degree-of-freedom analysis, mathematical and numerical solution of simultaneous equations, and flowsheeting packages such as HYSIM.
8. Be able to communicate technical ideas by means of drawings, reports, posters and oral presentations.
9. Be able to work effectively as a member of a team.
10. Know how to tackle open-ended problems.

APPENDIX 2
COURSE OUTLINE

Lectures (listed in sequence).

1.	7 Lectures	Introduction: chemical processes and equipment, units and dimensions.
2.	5 Lectures	Mass balances without reaction: oil refining, conservation of mass, systematic approach to solving prediction problems.
3.	8 Lectures	Energy balances involving heat and work: review of basic thermodynamics, development of energy equation, concept of enthalpy, heat capacity, heats of transition, steam tables.
4.	5 Lectures	Mass balances involving chemical reactions: phthalic anhydride production, conventions, limiting and excess reactants, tie substances, element balances.

5. 6 Lectures Computation: advanced True BASIC programming, use of spreadsheets.
6. 6 Lectures Numerical methods: root-finding methods.
7. 5 Lectures Energy balances involving chemical reactions: total enthalpy, standard heats of formation, isothermal and adiabatic reactors.
8. 5 Lectures Mass balances involving recycle: ethylene oxide production.
9. 8 Lectures Vapour–liquid equilibria and distillation: industrial alcohol production, vapour pressure, miscible and immiscible mixtures, equilibrium diagrams, lever rule, stills and stills in series.
10. 4 Lectures Liquid–solid equilibria: sylvinite processing, ternary diagrams, recovery of salts from brines.
11. 6 Lectures Humidifiction, drying and evaporation: pulp and paper production, psychometric charts.
12. 6 Lectures Mass and energy balances involving chemical equilibria: ammonia synthesis, chemical equilibrium.
13. 13 Lectures Chemical process industries: overview, plus specific processes.
14. 5 Lectures Process synthesis: basic concepts, reaction path synthesis, species allocation.
15. 5 Lectures Analysis of mass balances in non-reacting systems: degrees of freedom, number of independent variables, independent equations, and independent specifications, subsidiary relations.
16. 2 Lectures Analysis of energy balances in non-reacting systems.
17. 2 Lectures Multicomponent vapour–liquid systems: bubble point, dew point and equilibrium flash calculations.
18. 5 Lectures Analysis of mass balances in reacting systems: independence of reactions, specifications and balance equations, handling intermediate species.
19. 2 Lectures Analysis of energy balances in reacting systems.
20. 5 Lectures Manual and machine computation strategies: sequencing with complete or partial solution, extra root-finding methods, combined mass and energy balances.
21. 2 Lectures Use of flowsheeting packages: HYSIM.
22. 8 Lectures General: test feedback, communication.

Total: 120 Lectures

Afternoons (overall breakdown).

1. 23 Afternoons Tutorial sessions: solving problems as well as computer programming.
2. 8 Afternoons Design project: open-ended problem-solving, group work, communication.
3. 3 Afternoons Plant visits
4. 2 Afternoons Computation: spreadsheets, flowsheeting packages.
5. 2 Afternoons General: What is chemical engineering? Why did you do it? etc.
6. 2 Afternoons Tests

Total: 40 Afternoons

APPENDIX 3
ASPECTS OF COURSE ASSESSMENT

1. D.P. REQUIREMENTS:

- Satisfactory performance in 90% of tutorials.
- Average of at least 50% in computer assignments.
- Average of at least 50% in projects.
- Weighted average of at least 30% in the class tests.
- Attendance at 80% of CPI presentations and plant visits.
- Participation in CPI oral presentation.

Note: Where these D.P. requirements are only just met, 62% will be required in the examination to pass.

2. ASSIGNMENT OF MARKS:

Tutorials (10–12)	5%
Project (5)	20%
Class Tests (3)	25% (1–5%, 2–10%, 3–10%)
Examination (2 papers)	50% (25% each)
	100%

3. PROJECT WEIGHTING

• Design	10%
• Process Synthesis	2%
• Chemical Process Industries—Written	4%
• Computation/Flowsheeting	4%

APPENDIX 4
CHEMICAL PROCESS INDUSTRIES PROJECTS

1. Fertilizers (N-based and non-N-based).
2. Coal-based chemicals (fuels, chemicals).
3. Crude oil-based chemicals (fuels, chemicals).
4. Synthetic fibres and rubbers.
5. Oleo-chemicals (margarines, detergents).
6. Iron, steel, copper and nickel.
7. Sulphuric acid and explosives.
8. Forest and fermentation products (including paper).
9. Chlorine-based chemicals (PVC, chlor-alkali products).
10. Uranium and magnesium.
11. Soda ash and Portland cement.