SHARED TEACHING EXPERIENCES:

A SUMMARY OF THE CURRICULUM DEVELOPMENTS

CHEMICAL ENGINEERING EDUCATION PROJECTS COMMITTEE

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SUBCOMMITTEE CHAIRMAN

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TEACHING PROCESS DESIGN: A SURVEY OF APPROACHES TAKEN

INTRODUCTION

This is a biased interpretation of the fifty-two completed questionnaires that I received in response to my appeal for a sharing of ideas on the methods of teaching process design. This is not a strict reporting of the distribution of answers to the questions on the questionnaire. It is a sharing of the ideas and impressions that I gained from the data, and I have taken the liberty to include information from other sources.

The major themes of the report are what are the major difficulties encountered in teaching process design, and what suggestions and approaches could be or have been taken toward minimizing the difficulties. Many statements are referenced so that interested persons can write directly to a particular instructor for more information.

1. MAJOR DIFFICULTIES

Five major difficulties are encountered: time, choice of project topic, inadequate student background, vague teaching philosophy, and creativity.

1.1 Time

Most respondents pointed to time as the major difficulty encountered in design (12, 43, 48, 52)*. This was expressed also as "not enough time" (5, 24, 51) and "excessive demands on staff time" (1, 42). It is interesting to note that more than 50% of the universities already have between 200 to 450 calendar hours available for some type of project and that all but two have between 50 to 150 hours set aside for design.

1.2 Project Topic

The project should be

1. capable of being solved within the time allowed,
2. realistic and not make believe,
3. new and potentially of commercial interest rather than a rehash of well-established processes,

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*See Section 3.6 for respondent references.

4. one for which sufficiently accurate data are available such that some confidence can be placed in the answer.

Furthermore, the staff must be relatively familiar with the technology of the process.

The second most popular difficulties encountered were the lack of reliable data (13, 46, S-3)** and the availability of good projects (10, 29, 47).

1.3 Inadequate Student Background

Students entering a design course often have inadequacies in

1. cost estimation and engineering economy (24, S-3),
2. rule-of-thumb design (24, S-3),
3. equipment design methods,
4. use of the library,
5. report writing or oral communication,
6. creative thinking.

1.4 Vague Teaching Philosophy

Process design is difficult to teach. We have not decided what topics can be taught and what cannot be taught in design or what experience the staff should present to the students (Asimow, C-1 p. 40).

Once we decide upon the topics and the experience, how can we teach it? Fisher found that, much as he wanted to share his design experience with the students through lectures, it was necessary and desirable to arrange student assignments so that the students discovered some of the pitfalls of process design and management themselves(2). Some instructors found that the informal discussion sessions with the students were very rewarding (47). Others found that when lectures were offered upon request by the students, few lectures were requested; the students wanted to get on with the job (S-1, W-1).

From the answers to the questionnaire only two general conclusions can be drawn:

1. the most common ratio of lecture to total calendar time is about 0.25
2. the type of guidance given in any meetings held during the project is "how the work should be done" in 85% of the universities. The other 15% of the universities prefer to use these meetings to discuss "how the work should have been done".

**Alpha-numeric symbols refer to papers and books listed in Section 3.4.

No other conclusions can be made because of the variety of approaches taken for the amount of staff guidance (student to staff ratio and the number of meetings), and the type of project used to illustrate design.

It seems that there is a lot of experimentation being done in teaching techniques; it is hoped that the results are shared because so many questions on teaching philosophy remain unanswered.

1.5 Creativity

A final major difficulty is creativity. Most universities reported a concern for the presence of it in their approach. My first impression was that "creativity" has a different meaning to different people. Two questions on the questionnaire were included to check for consistency in the respondent's definition with my idea of creativity. Often there was not consistency. For this work I chose Taylor's definition "creativity is the process of generating better alternatives according to an acceptable criteria" (T-1). The opportunity to generate alternatives must arise either from the problem specification (25) or from a willingness to generalize a problem specification to allow for alternatives.

The first task is to offer the opportunity to be creative. This demands not only student time but extensive staff time (51). Many of the topics chosen for the design project have more analytical than creative opportunities. For example, the use of the AIChE or IChE (London) problems and problems where flow diagrams, assumptions and type of equipment to design are specified restrict the opportunity for the generation of alternatives. Despite the popularity of this type of project, I was pleasantly surprised by the efforts made by about 35% of the universities to use unstructured, openly defined problems.

Even if the problem has few restrictions, it is difficult to encourage the students to grasp the opportunity to be creative. Several examples exist where creative problems were offered but all the students chose the same, fairly well-defined process to solve the problem (W-1). Some try to keep the opportunity for creativity alive by posing the right questions to the students (2, S-3) and getting the students to have confidence in out-of-the-ordinary decisions. But how can we get the students to pose those questions themselves?

Hence, we have difficulty in deciding what we mean by creativity, in allowing it in the problem specification, and in encouraging the development and adoption of novel but economical designs.

2. COMMENTS AND SUGGESTIONS

Some comments and suggestions are made about the major difficulties listed.

2.1 Time

In general, I was pleasantly surprised at the amount of time allowed for professional development courses**. I had expected the time to be around 100 hrs., and this turned out to be approximately the minimum time spent. Some devote three to seven times this amount and seem to make this group of subjects a major consideration. For this total time about 50% of the colleges have both research and design projects.

I had expected that hardly any unit processes or technology courses would be offered and was surprised to see that 35% of the universities offered this. I was disappointed in the amount of engineering economy presented and with the emphasis that seemed to be placed on it when it was given. I gained the impression that often the economic analysis was of minor interest even though 90 to 95% reported that economics was part of the student experience.

From studying the courses offered I think that perhaps we are not effectively using the total calendar time available because not sufficient time is available to do both research and design effectively, and because too much new course work has to be introduced in the design project to leave sufficient time for the students to tackle the project.

Several suggestions for minimizing the difficulty of not enough time for design are

1. allow more curriculum time. Some have done this, but even then they believe lack-of-time to be the major difficulty.

2. more effectively use the student's time by

   a. having the students work in groups. This has been the most widely accepted approach. Students at about 90% of the schools tackle design projects (other than the AIChE problem) this way. The danger is that each student will not have equal opportunity, or that he will be working in one specialty area and learn little, or that he must depend on others who may fail to pull their weight. This sometimes means that some students are worse off working as a member of a group than if they worked alone on less ambitious problems. Many try to get around this by rotating the chairman of each company group. One tried using all of the company groups together to act as each other's consultants and as an idea sounding-board (51).

   b. using smaller design projects or a well-planned, guided program instead of a large project. This is discussed in Section 2.4

**For definition of terms see Section 3.5.

3. turning open-ended problems into well-defined analytical exercises. This removes the need to decide upon the process because the process is specified; one does not have to look for physical properties or kinetic data because they too are given. In fact, the problem is so defined that there is very little opportunity for creativity at all. This is the approach taken by about 60% of the colleges when they offer design projects and by 75% of the colleges when they specify problems for part of a design course.

Concerning the staff time requirement, one can try to minimize the staff load by encouraging all of the staff to participate. This not only makes the teaching load more balanced and provides a wider background of experience but presents a greater chance to give creative problems. About 5% of the departments use all of the staff on the design project (excluding fundamental research projects) 45% use more than one staff member. The question we need to try to answer is "is the student benefit from the course worth the required staff effort?".

2.2 Project Topic

The project topics listed by many respondents were interesting and sound challenging. For example,

a. develop and design processes for the utilization of a raw material common to the area, e.g. salt in Southern Ontario or uses for Missouri oak.

b. develop and design processes for production of a material required in the area, e.g. fertilizer.

c. develop and design processes to meet some realistic need, e.g. soft detergents, styrene, acrylonitrile (in Canada in 1964), water and oxygen on the moon for the space program, water desalination for an emerging country.

d. let the student do a market survey and decide upon his own product and production rate.

One conclusion that can be made about the design topic is that the students enthusiastically attack a problem that they think is significant rather than academic. Dartmouth found this in their work on medical devices for the physically handicapped (S-1). Some realism can be generated, even for work on well-known processes, by the use of an outside industrial judging committee for the final report (S-1)(W-1), or by the application of novel analytical or computational methods such as the digital computer simulation of the CIL sulphuric acid plant with the help of the PACER executive program (S-2). Nevertheless it is one thing to think up ideas of realistic projects, but it is quite a different problem to obtain accurate background experience to give them confidence in supervising the project. Most of us, rightly or wrongly, try permutations and combinations of the processes with which we have worked.

Some suggestions for selecting and obtaining background information are

1. use government agencies to help supply the necessary information. For example, the Technical Information Service of the National Science Library probably would help Canadian staff members.

2. study the import-export statistics and try to forecast the new products for the country,

3. encourage the staff to take sabbatical leaves in industry. Although this often jeopardizes research, several have done this.

4. obtain cooperation from industry in supplying technical information about processes, physical property data, cost data and design manual information. Several schools have been able to enjoy good liason on certain projects (S-2)(W-1). Some visit plants similar to the ones on which the students are working and discuss technical details after the students have had some experience with the project (27)(44).

5. invite individual guest lecturers from industry for special lectures (27). This can disrupt any lecture program but, with care, can bring a wealth of pertinent industrial experience to the project.

6. invite engineers in as consultants, not to give lectures, but to contribute to the discussion sessions with the individual project groups (36).

7. assign the project supervision to a part-time instructor from industry or consulting firm (23).

8. have all the staff contribute to the project and hence gain from all of the staff experience (24)(S-2).

9. arrange for one-week seminars in August during which industrial specialists on one process would update design instructors on this process. This could be a cooperative industrial program with visits to several different companies engaged in this process.

These are some suggestions to improve the background information.

2.3 Inadequate Student Background

We expect a course in process design to do too much. We shove know-how and technology, rule-of-thumb design and equipment design out of the engineering science curriculum. We tend to look on design courses or projects as the "great finishers"; we add the odds and ends that we did not get a chance to cover elsewhere. Therefore, instead of the student coming into the design project with an understanding of engineering economics, industrial problems and technology, equipment design, optimization and methodology for handling complex problems, he must pick this up in the design course. Furthermore, the students usually solve analytical not creative problems in their preceding courses, yet we expect them to become creative in the design project.

I feel that the professional development program should prepare the student for responsibilities in the expansion of process industries, in the efficiency work with existing plants, or in research and development. Projects in any one of these three responsibilities would be worthwhile provided the project followed a core* of professional development subjects (just as we have engineering and science core subjects). Some suggestions for preparing the students for the project work and thereby satisfying the professional development core program are

1. use the summer period for
   a. required reading courses with exams at the end of the summer (7),
   b. reports of engineering experience,
   c. cooperative industrial training.

2. give special courses in the subject, e.g. equipment design (25) (33), technical communication (32)(24).

3. offer visits to industries and require reports of the visit (33).

4. add to each transport phenomena course experience in equipment design, cost estimation and rule-of-thumb design.

5. arrange for functional analysis of processes together with day long "schools" in industries to study in detail one part of the process.

2.4 Vague Teaching Philosophy

Many interesting experiments are being done. Some experiment with the type of problems used to teach design. The traditional lecture plus design of equipment, and the group project of one process, although still popular, have four interesting challengers:

1. a series of projects that start simply and increase in difficulty and time requirement while the instructor's guidance reduces.

2. case studies where a series of projects of approximately equal length and degree of difficulty are tackled (S-3).

3. research and development laboratories where the emphasis is on process (not on engineering science fundamentals).

*An enumeration of courses to be included in the professional development core is given in Section 3.5.

4. plant design of one large plant tackled by individuals or as an all staff-all student class project.

For the actual mechanics of teaching, I feel that we should experiment by

1. offering a detailed project only after all of the core material has been given,

2. maintaining a high staff to student ratio (preferably having all staff participate under the supervision of one or two coordinators),

3. encouraging frequent discussion sessions (either informally or formally) with the emphasis on how they did the work. We could try to arrange for industrial engineers to attend these sessions,

4. try to simulate industrial working conditions, encouraging the students to work in a pleasant design room (rather than at home), to work a set number of hours during the week and have them match their accuracy of calculations to that time (W-1).

2.5 Creativity

Many are concerned that they have creative projects. Yet the students should have some experience in creativeness before they reach the design or research project. Some suggestions are:

1. offer short problems such as trouble-shooting problems in unit operations courses and laboratories (7) or in engineering economics courses (W-2). Project and equipment design for unit operations laboratories can supplement the traditional three hour experiments on unit operations equipment (24).

2. use functional analysis of processes to encourage the invention of other process systems.

3. set up a creative atmosphere (Arnold, C-1, p. 95).

Some comments and suggested methods to minimize the difficulties encountered in teaching process design have been given. The next section is a summary of the answers given by respondents to the questionnaire.

3. Background Information

3.1 Time Available

The time set aside in the undergraduate curriculum can be arbitrarily divided into three portions

1. humanities (including economics)

2. science and engineering science (including unit operation but excluding equipment design and project work)

3. professional development (PD)

The professional development portion consists of some professional development core topics and a project laboratory. The core includes engineering economy, use of the library, written and oral communication, mathematical methods of optimization, project planning and complex problem methodology, equipment design (both detailed and rule-of-thumb), an appreciation of chemical industry and technology and some experience in creativity. The project laboratory draws from a background of core material to illustrate one or more of the three major engineering responsibilities: expansion of processes; efficiency work on existing plants, and research and development.

The total calendar time set aside for professional development courses by different universities is indicated in Figure 3-1. There seem to be three general trends

49%	of the schools	allow between 80 and 180 hours
31%		allow between 200 and 250 hours
20%		allow more than 350 hours

There seems to be no general trend in the way the total time is spent. (Elective courses were not included in this analysis except where there seemed to be a good chance that the students would choose the course.)

3.2 Method of Teaching

Four topics are considered pertinent to the method of teaching: the ratio of lecture to laboratory hours, type of problems used, guidance for projects and the creativity allowed.

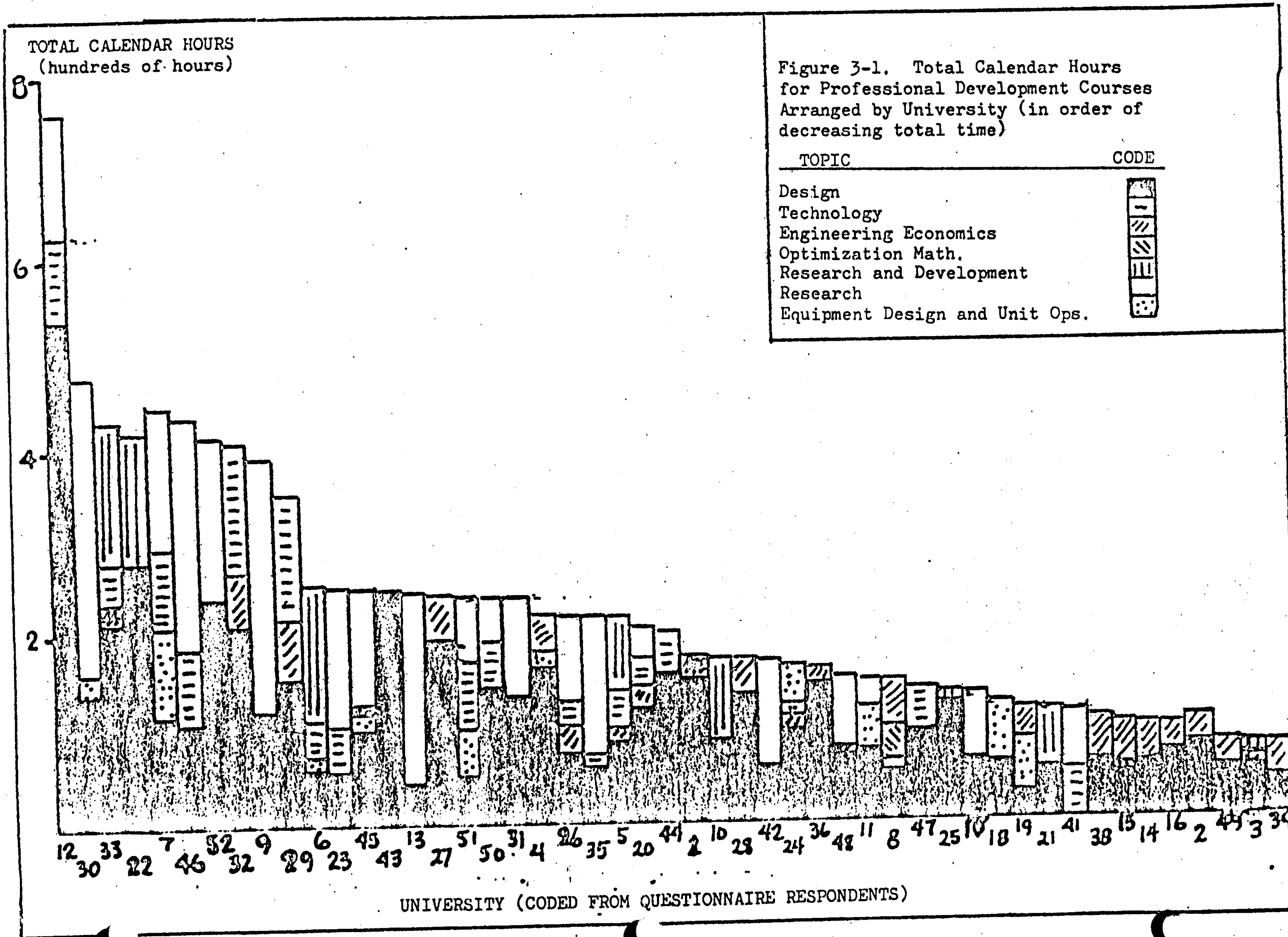


Figure 3-1. Total Calendar Hours for Professional Development Courses Arranged by University (in order of decreasing total time)

3.2-1 Type of contact for the Design Program

Figure 3-2 illustrates the ratio of formal lectures to total calendar hours available. Included in these data are both design project laboratories and design courses. The lecture time used was not the nominal lectures specified in the calendar but the realistic estimate of the respondents.

The most popular ratio was 0.20 to 0.30 lectures / total time.

3.2-2 Type of Problem Used

Five approaches are taken in handling design

1. lecture plus homework assignments on equipment design or design of small plant sections,
2. one large plant or process design,
3. guidance through a series of problems of approximately equal length and difficulty (case studies),
4. a series of problems of increasing length and difficulty (guidance is reduced as time progresses),
5. one large research and development project with the emphasis on process or pilot plant rather than on engineering science fundamentals.

Combinations of these approaches are also taken. Table 3-1 is a summary of the approaches taken by the respondent schools. The numbers refer to schools listed on the Questionnaire Respondents. An underline means double entry of the number; i.e. more than one approach were taken or it gives the type of projects included in an approach.

3.2-3 Guidance for Projects

Three indications of the philosophy of guiding projects are the student to staff ratio, the number of formal or informal meetings, and the purpose of the meeting.

Student to staff ratios are displayed on Figure 3-3. The trend seems to be to keep the ratio less than 10 to 1. This could be because

1. the classes are less than 10,
2. we are gradually starting to use more than one staff member on the projects,
3. all staff members contribute.

The definition of staff used here does not include graduate assistants.

Problems Used / Problems Tackled by Students as:		Case Studies Problems of Approx. Equal Length	Series of Increasingly Difficult Problems	One Large Project		Research and Development	Unit-Ops Equipment Design plus Lectures
				A.I.ChE.	Other		
INDIVIDUAL		8 15 17 23 24 28 38 44 49	2 3 4 6 8 13 38	6 9 10 13 15 18 28 33 34 7	24, 50, 51	33 45	4 5 10 11 20 21 25 30 34 36 45
GROUPS	2 to 3	18 22 [illegible] 52			3 4 12 25 26 29 31 36 43 44 47 48 49 52	22	
	4 to 5	1 33			2 14 32 33 46	5 10 21 24	
	6 to 7				7		
CLASS (Or 7)		22 (10)			24		
UNKNOWN SIZE					6 19 20 27 35	27	

TABLE 3-1 TYPES OF PROBLEMS USED BY RESPONDENT UNIVERSITIES TO TEACH DESIGN. NUMBERS REFER TO LIST OF QUESTIONNAIRE RESPONDENTS. UNDERLINES MEAN DOUBLE ENTRY IN THE TABLE.

The number of formal or informal meetings between staff and student are shown in histogram on Figure 3-4. Some have as many meetings as 30, but the majority use between 5 and 15 meetings.

The meetings were predominantly used to discuss how the work could be done, i.e., guidance about future work (85% of respondents). Fifteen per cent of the universities use the meetings for feed-back of how the work could have been done.

Table 3-2 gives some indication of the different opportunities of creativity offered because of the way the problem was specified. Figure 3-5 presents the frequency distribution of these levels of creativity for design projects and for problems used in the design course.

3.3 Student Experience

The topics the students experienced during either a design course or a design project and the percentage distribution for the universities are given in Table 3-3.

Table 3-2 Indication of Several Levels of Creativity Allowed by the Method of Problem Specification.

Degree of Creativity	General Examples of Problem Specification	Specific Examples
1	1. no variables specified eg. design a plant to make 25 t/d of a	
2	2. several variables given eg. design a plant to make 25 t/d of A with x process.	Case Study, Chpt. 2, (ref. 4)
3	3. limited variables given such as flowsheet, computer programs, yield and kinetic data, properties, temp. at some places; pressures at all places, costs, costs equations.	AIChE Problems Case Studies, Chpt. 3,4 Ref.4 IChE (London) Problems.
4.	4. most variables specified.	

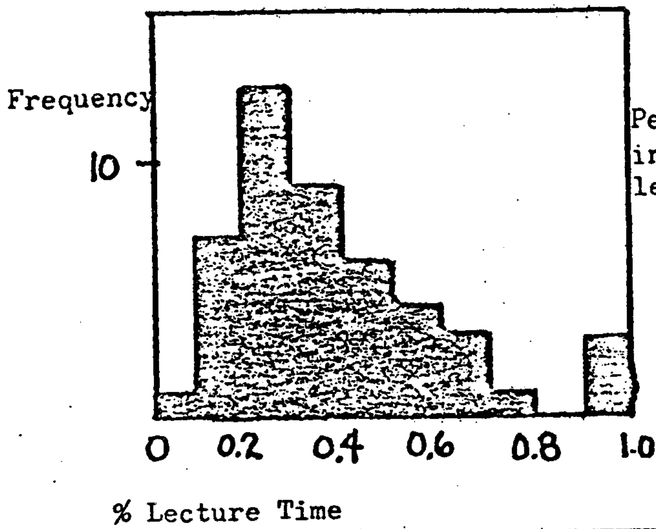


Figure 3-2
Percentage of total calendar time spent in lectures (including estimate of lecture time calendar lab. periods).

Figure 3-3
Student to staff ratio in project work.

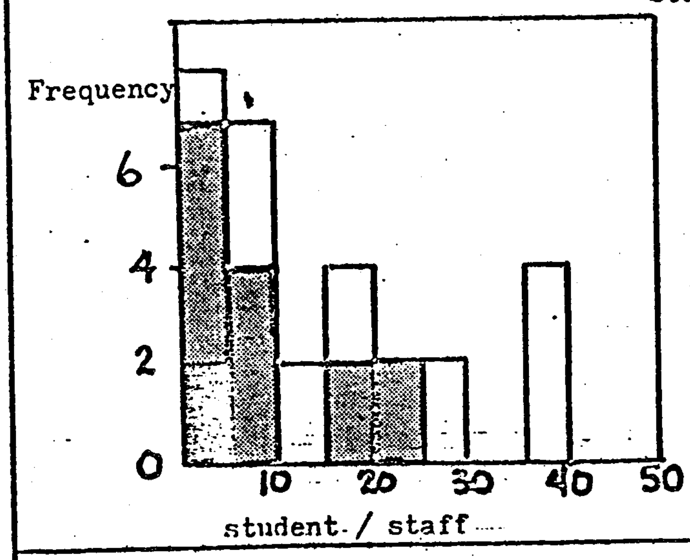


Figure 3-4
Number of discussion meetings held between supervisor and students during design projects (excluding research projects).

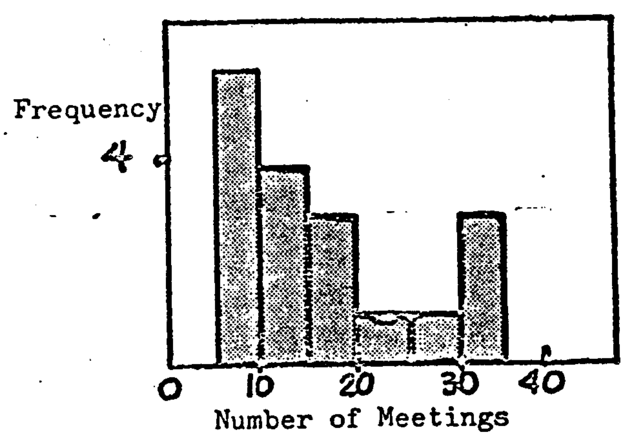
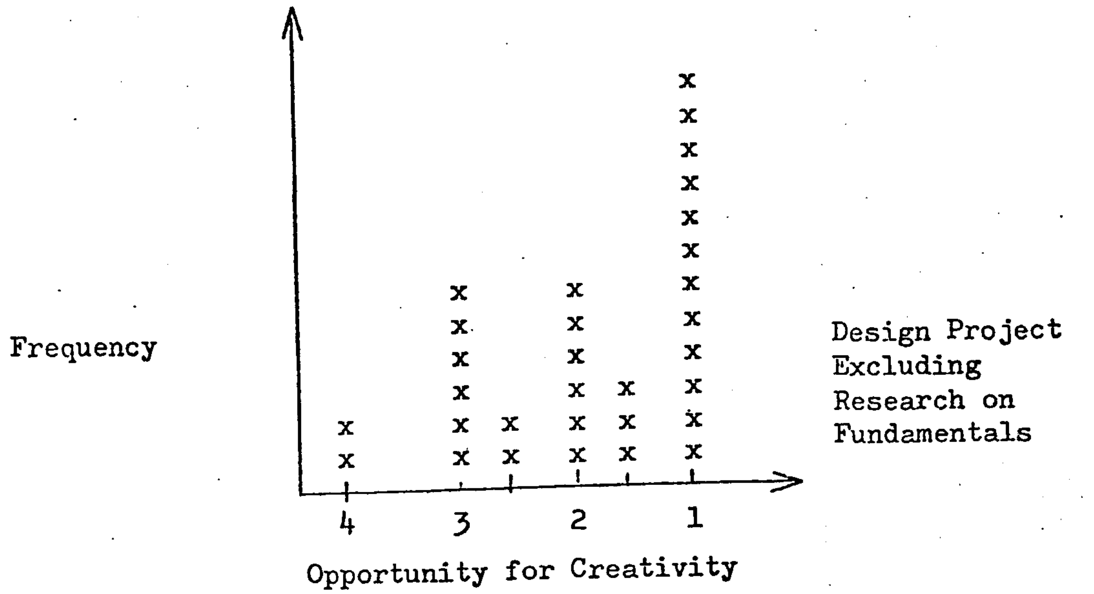


Table 3-3 Topics the Students Experienced

Topic	Design Course	Design Project
1. Optimization	61%	75%
2. Decision Theory	61%	45%
3. Computer Programming	50%	60%
4. Rule-of-Thumb-Design	70%	70%
5. Mechanical Design	15%	35%
6. Working drawings / layout	-	25%
7. Scale Model Construction	20%	25%
8. Piping Layout	25%	40%
9. Cost estimates of alternatives	85%	75%
10. Cost evaluation of project	95%	90%
11. Equipment design	65%	
12. Process Design	80%	
13. Use of Library	80%	
14. Report writing	—	15%
TOTAL NUMBER OF UNIVERSITY REPLIES	31	19


Frequency
Design Project
Excluding
Research on
Fundamentals
4
3
2
1
Opportunity for Creativity

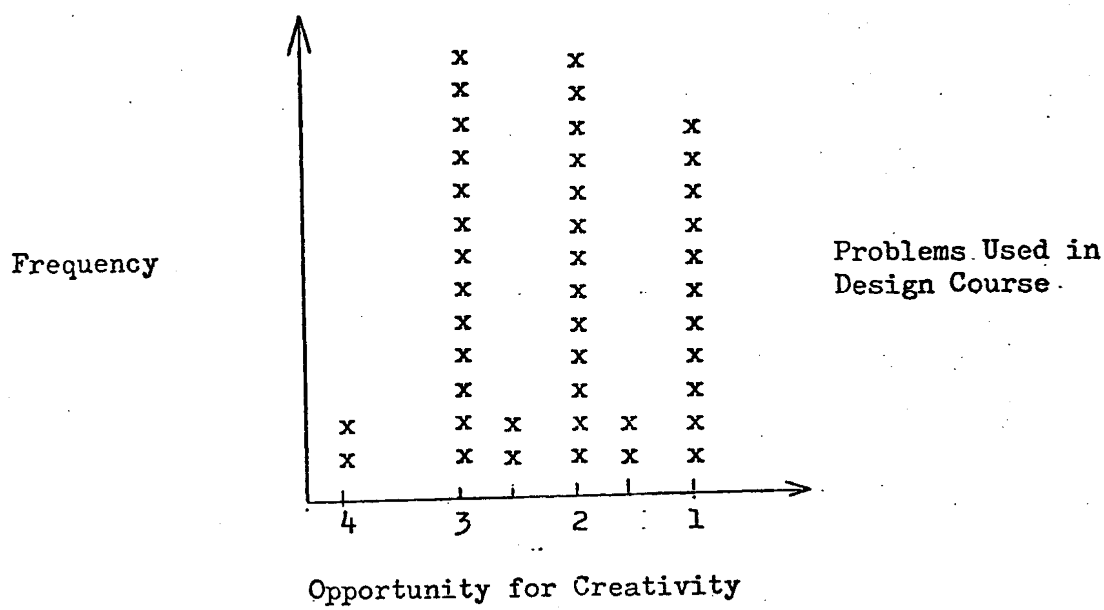

Frequency
Problems Used in
Design Course
4
3
2
1
Opportunity for Creativity

Figure 3-5

3.4 References

C-1. Case Institute of Technology, "Engineering Design Education", Proceedings of the Conference, sponsored by Case I. T. and ASEE (1960).

S-1. Shannon, P. T., Thayer School of Engineering, Dartmouth College, personal communication (1965).

S-2. Shannon, Crowe, Hamielec, Hodgins, Hoffman, Johnson and Woods, "A Study of a Contact Sulphuric Acid Plant Using PACER", Final year project report, Department of Chemical Engineering, McMaster University, Spring (1965).

S-3. Sherwood, T. K., "A Course in Process Design", The MIT Press, The Massachusetts Institute of Technology, Cambridge (1964).

S-4. Silveston, P. L., Personal Communication about the Desalination Plant for Lagos project. University of Waterloo, Waterloo, Canada (1964).

T-1. Taylor, G. A., "Managerial and Engineering Economy", Van Nostrand Company, Toronto. (1964).

W-1. Woods, D. R., and A. E. Hamielec, "An Evaluation of An Approach to Plant Design", Faculty of Engineering Report No. 10, Mc Master University (1965).

W-2. Woods, D. R., "A Complement to Design: Trouble-Shooting Problems", Faculty of Engineering Report No. 18, McMaster University, May (1965).

3.5 Definitions

Calendar time : time allowed in calendar for lectures and laboratory periods. This does not include expected hours of preparation, homework assignment or hours allotted for the project over and above that indicated in the calendar.

Creativity : the process of generating better alternatives according to an acceptable criteria (T-1).

Design Course : design examples and topics covered predominantly through lectures.

Design Project : design topics and topics covered predominantly through problem workshops or laboratory experimentation.

Engineering Economics	:	capital and operating cost estimation, time value of money, applied economic balances.
Professional Development Courses	:	courses other than humanities, science and engineering science courses that can be related to the professional activities of a graduate engineer.
Professional Development Core Subjects	:	includes engineering economics, project planning and complex problem methodology, equipment design, an appreciation of industry, use of the library, mathematical methods of optimization, experience in creativity, written and oral communication.
Time allocation based on Calendar Time	:	The hours spent in lectures as specified by respondents to questionnaire. This does not necessarily agree with the lectures hours stipulated in the calendar.
Topic allocation based on Calendar Time	:	The hours spent studying a given topic as specified in or estimated from the questionnaire. This does not necessarily agree with the course title stipulated in the calendar.

3.6 Respondents to Questionnaire

1. Alabama, University of; Dr. James H. Black
2. Alberta, University of; Dr. D. G. Fisher
3. Arizona State University; Dr. C. O. Reiser
4. Arizona, University of; Dr. R. M. Edwards
5. Auburn University; Dr. R. E. Wingard
6. Brigham Young University; Dr. Dee. H. Barker
7. British Columbia, University of; Dr. K. L. Pinder
8. Carnegie Institute of Technology; Dr. Carl C. Monrad
9. Clarkson College of Technology; Dr. Joseph Estrin
10. Clemson University; Dr. C. E. Littlejohn
11. Colorado, University of; Dr. R. Curtis Johnson
12. Cornell University; Dr. Robert York
13. Delaware, University of; Dr. T. W. F. Russell
14. Drexel Institute of Technology; Dr. E. D. Grossmann
15. Florida, University of; Dr. R. A. Keppell
16. Georgia Institute of Technology; Dr. G. L. Bridger
17. Gonzaga University; Dr. R. S. Rosler
18. Illinois Institute of Technology; Dr. C. J. Marek
19. Iowa, State University of; Dr. James O. Osburn
20. Louisville Speed Scientific School, University of; Dr. Gordon C. Williams
21. Manhattan College; Dr. F. Derbenwick
22. Massachusetts Institute of Technology; Dr. E. R. Gilliland
23. McGill University; Dr. E. Nenniger Jr.
24. McMaster University; Dr. D. R. Woods
25. Michigan, University of; Dr. Dale E. Briggs
26. Mississippi, University of; Dr. Frank A. Anderson
27. Missouri, University of at Rolla; Dr. M. R. Strunk
28. Missouri, University of; Dr. George W. Preckshot
29. Montana State College; Dr. Lloyd Berg
30. New Brunswick, University of; Dr. D. D. Kristmanson
31. New Hampshire, University of; Dr. O. T. Zimmerman

    North Carolina State, Raleigh; Dr. E. M. Schoenborn
32. Nova Scotia Technical College; Dr. I. J. Harris
33. Ohio State University; Dr. Aldrich Syverson
34. Oklahoma State University; Dr. R. N. Maddox
35. Ottawa, University of; Dr. F. Talbot
36. Pennsylvania, University of; Dr. M. C. Molstad
37. Queen's University; Dr. R. H. Clark
38. Rensselaer Polytechnic Institute; Dr. Stephen Yerazunis
39. Rhode Island, University of; Dr. Niels Madsen
40. Royal Military College of Canada; Dr. W. F. Furter
41. Saskatchewan, University of; Dr. N. N. Bakhshi
42. South Carolina, University of; Dr. B. L. Baker
43. South Dakota School of Mines and Technology; Dr. R. F. Heckman
44. Texas, Technological College; Dr. J. A. Renard
45. Toledo, University of; Dr. C. W. Balch
46. Toronto, University of; Dr. M. Wayman
47. Tufts University; Dr. Kenneth A. Van Wormer
48. Washington, University of; Dr. L. N. Johanson
49. Waterloo, University of; Dr. P. L. Silveston
50. Western, University of; Dr. K. A. Shelstad
51. Windsor, University of; Dr. Alex Gnyp
52. Yale University; Dr. Randolph H. Bretton