Int. J. Engng Ed. Vol. 17, No. 3, pp. 261–266, 2001
Printed in Great Britain.
0949-149X/91 $3.00+0.00

Group Project Work in Engineering Design—Learning Goals and their Assessment*

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This paper describes comprehensive marking criteria, which have been developed over a number of years, for the assessment of an innovative undergraduate course in engineering design. The course assessment is based almost entirely on group project work. A strong emphasis is placed on oral and visual communication skills during the first semester, which are complemented by a concentration on more technical engineering design material in the second semester. The paper begins with a description of why the course was developed and how it fits within a conventionally taught and examined undergraduate degree programme in Industrial Engineering and Information Systems. This initial descriptive material is followed by a discussion of the learning goals of each element of the course and details of the marking criteria adopted. Finally, there is a critical review of the assessment methods used.

INTRODUCTION

IN COMMON with many undergraduate degree programmes in Europe, the four-year Bachelor of Engineering programme in Industrial Engineering and Information Systems provided in Galway contains a strong core of formally taught and examined courses. Formal teaching methods have, indeed, much to commend them. There is a great deal more, however, to the education of engineers than the ritual regurgitation of information for final examinations. From a purely pedagogical point of view, one of the main drawbacks of formal teaching methods is that each course within a degree programme is self-contained and there is often little, if any, integration of material between individual courses or modules within a particular programme year. Too often, there is also poor development of material from one year to the next and, frequently, there is only a tenuous connection between the syllabus and students' perception and experience of the real world. In other words, there is a strong concentration on specific learning methods and the exclusion of others.

According to Entwistle, research on student learning has identified two dominant orientations: knowledge-seeking, and understanding-seeking [1]. Those who have a knowledge-seeking orientation search for facts and information, they are not interested in speculating, playing with ideas or searching for deeper meanings. By contrast, those with an understanding orientation are less interested in facts, they relate what they learn to their earlier experience, and explore potential connections, linkages and discrepancies. Those who learn through understanding tend to be intrinsically motivated rather than responders to a system [2]. There is an obvious parallel, here, with de Bono's critical thinkers and generative thinkers: on a practical level, critical thinkers (describers) tend to stay within the bounds of the topic under discussion, whereas generative thinkers (doers) seek to test their knowledge in the real world of existents [3]. It is apparent that formal teaching and examination methods tend to alienate those who learn through understanding. This characteristic bias has been commented on by many observers (see reference [4], for example); it is particularly noticeable within scientific and engineering education.

Pedagogical factors, however, are not the only ones that must be considered in the education of engineers. There are also professional requirements to be satisfied, a question of transferable skills, the issues of relevance, motivation, professional training, research, the contribution to life-long learning, etc. Each of these factors demand attention. In order to find a balance, each society must make judgements on the relative worth of these factors and, given sufficient freedom, act accordingly. At the University of Aalborg, for example, a complete switch from formal teaching methods to project-based teaching has been made throughout the whole degree programme [5]. Also, where funding allows, new degree programmes can be offered with a central core based on the more creative aspects of engineering such as design [6].

* Accepted 26 August 2000.

A COURSE IN ENGINEERING DESIGN

Degree programme intake, structure and content

In Galway, a typical eighteen year-old university entrant would probably have seven or more subjects at School Leaving Certificate level, including three languages. The vast majority of entrants do so straight from secondary school. They would normally have little or no direct experience of engineering activities. All undergraduate engineering programmes offered in Galway span four years, the first two being largely common between the various disciplines, and which concentrate on basic engineering science, mathematics, information technology, etc. Broadly speaking, it is the syllabus in third and final year that gives each degree programme its individual identity and flavour.

The BE programme in Industrial Engineering and Information Systems (IEIS) contains several courses and modules that are not commonly found in other, more traditional branches of engineering:

- Industrial Management
- Organisational Development
- Managerial Economics
- Ergonomics
- Human Biology
- Operations Research
- Reliability
- Safety
- Quality
- Communications.

In final year, there are also optional courses in:

- Languages (French and German)
- Accountancy and Finance
- Industrial Psychology
- Industrial Sociology.

There is also an industry-based project in final year, which contributes 20% to the assessment in that year. In the Engineering faculty, each programme year comprises a number of courses and/or modules which combine to a total assessment of 1000 marks. Ten years ago, there would typically have been 10 courses of 100 marks each. There have been numerous changes since that time, most notably the introduction of semesterisation, an increase in the number of modules (material taught and examined during a single semester), and an introduction of the European Credit Transfer System (ECTS).

Why design?

A course on Engineering Design was perceived as the means by which students could be exposed to the activity of 'doing' as well as of 'thinking', i.e. the opportunity would be provided for students to learn through understanding. Initial experience with the course was very positive and this provided sufficient impetus to develop the approach further [7].

Design is an activity, not a subject heading. To design anything, one must become actively involved with the material one is working with, whether it be a computer program, a piece of automatic equipment, a ball of clay, or an evaluation of ideas. In other words, an involvement in the design activity necessarily involves the participant in the real world of 'things' and 'concepts'. To help focus on these (and other) ideas, the author has offered the following definition of design within an engineering context [8]:

> Design is the purposeful means and end-result of realising a product or process that satisfies acknowledged and stated criteria.

This definition makes it clear that the following four elements are identifiable within the design activity:

- development of starting criteria (specification stage);
- a purposeful search for solutions (conceptual design stage);
- the description of a chosen solution (detail design stage);
- an assessment of the solution against the starting criteria (evaluation and build).

In order to permit students to experience the activity of design it is necessary to break away from formal teaching and examination methods. Project-based learning offers an ideal pedagogy for teaching design. The attractions of project-based learning activities are: they allow a student (or group) to collect and collate information, to develop alternate strategies, to make prognoses and test them, to prepare reports and present their case to others. Project-based learning, in other words, is not only an effective means of teaching design but can also be a vehicle for the synthesis of ideas. Intellectually, a project-based pedagogy permits the brighter students to extend themselves to their full potential—a potential, which is usually way beyond the limited horizons of formally taught courses. And for the less able students there exists an opportunity to substitute quantity for quality by putting in extra hours of study on the project.

Initial course structure

A standalone, continuously appraised, project-based course on Engineering Design was introduced in September 1989, and was valued as the equivalent of one full course (100 marks). The course ran over two twelve-week semesters. Details of the course structure, content and teaching methodology have been published elsewhere [9–11] and require only a brief description here.

During the first part of the course, self-determined groups of about ten students each selected an environment-based project to study. Topics covered in this area have included waste management and recycling, pedestrian and vehicular traffic problems, sick building syndrome, marine pollution, computer viruses and student timetables. The second major part of the course involved smaller groups (of 2 to 4 students). These projects cover a wide range of material and demand the acquisition of new knowledge, techniques and skills appropriate to the scope and depth of the project itself. Students were given feedback through regular project meetings and via comprehensive comments on their written reports. Occasional lectures were given to the class as a whole on specific design topics, particularly in the first few weeks. Over the remainder of the academic year students may have undertaken up to two or three design projects depending on the time taken to achieve agreed objectives within each project.

Current course structure and contents

Numerous changes have been made to this third-year course since its introduction in 1989. However, the underlying emphasis on project-based teaching has remained unchanged. A major revision in structure and format was introduced in September 1996 to accommodate both the adoption of semesterisation and an increased emphasis on communications within the Engineering faculty. A full description of these changes has already been published [12]. In brief, the current Engineering Design course has been increased in value to 20% of the total assessment at third year.

At the moment, the graphical communications element consists of basic instruction in the use of AutoCAD, which occupies 2 hours per week. The primary learning goal, here, is to increase the level of manipulative proficiency of students to a minimum benchmark standard and to build upon the practical drawing board experience they gained in earlier years of study. These aims are achieved by employing a contracted, outside service provider.

In regard to instruction in oral and written communications, the initial part of the module is geared towards career development: the preparation of a CV, a business letter, a memorandum, and a job application. The advice and examples provided by the instructor are also readily supplemented by available texts (see reference [13], for example). The learning goals of these initial assignments are self-explanatory and make up 25% of the overall assessment of this module. The remaining 75% of the marks are allocated to group project work, which is assessed by means of individual oral and written presentations. These projects are deliberately chosen to get students to look outside the classroom, and to encourage them to examine the impact of design decisions on society at large. As with the AutoCAD module, instruction in oral and written communication is also undertaken by a competent, outside service contractor. The projects themselves, however, are jointly managed and assessed by the service provider and the academic director. These projects run for a further 6 weeks: each week consists of 1 hour of instruction, which is followed by a scheduled meeting with each project group lasting 30 minutes. These meetings permit some discussion and feedback on the project itself, assistance with information sources, and a general appraisal of the group and of each individual student. Two weeks are allowed at the end of this period for preparation of the oral and written presentations. Each oral presentation is of 5 minutes duration; the written report is not to exceed 10 pages.

Finally, we come to the second semester. A list of design projects is presented to the class during the first week. Students work in pairs and, occasionally, a pair suggests a design theme of their own. These projects occupy the whole 12-week semester, and are completed by an oral presentation and written report. Unlike the first semester, however, there is no restriction in the length of the written report. The oral presentation is also of longer duration: 20 minutes for the presentation, plus 5 minutes for answering questions from the examiners. For most of the semester, there is a weekly lecture on specific aspects of the design activity: specification, methodology, organisation, time management, evaluation, etc., etc. There is a major difference in the format and in the assessment of this design work in comparison to communications module. Instead of regular weekly meetings with each project group, the concept of 'client' meetings has been introduced: student 'consultants' only arrange to meet their 'client' when they think they have something to discuss.

It should be apparent from the above that each project demands a different mix of student learning. In general, however, each project contains the potential for a student to span the whole cognitive domain as in Table 1.

ASSESSMENT

Details of the marking scheme adopted have been published earlier [12, 14], although some minor changes have been made more recently. The following paragraphs concentrate on how the specified learning goals are assessed; they also provide a summary of the marking schemes.

Graphical communications

Competence with AutoCAD is assessed through two assignments of 10 marks each, which are returned during the instructional period, and a 1-

Table 1. Hierarchy of the cognitive domain [2]

6 Evaluation	Ability to make a judgement of the worth of something
5 Synthesis	Ability to combine separate elements into a whole
4 Analysis	Ability to break a problem into its constituent parts and establish a relationship between each one
3 Application	Ability to apply rephrased knowledge to novel situations
2 Manipulation	Ability to rephrase knowledge
1 Knowledge	That which can be recalled

hour end-of-semester hands-on examination valued at 30 marks. The examination demands the construction of the usual orthographic views of a typical engineering component or assembly, and only the most skilled would manage to complete the drawing in the time available.

Oral and written communications

The breakdown of the available 50 marks for the module is as follows:

Grammar quiz	5
Short assignments (4 × 5 marks)	20
Oral presentation	10
Written report	15

Individual oral presentations, based on the content of the report, take place in weeks 11–12. Students are required to dress formally and present a well-groomed appearance. The entire class is expected to attend the presentations. Immediately after each talk, feedback on content and performance is provided by the two assessors, one of whom is the communications instructor, the other being a professional engineer. Each presentation is of 5 minutes duration and is videotaped for subsequent evaluation by both instructors and students. Marks are awarded using the scheme presented in Table 2.

Peer assessment, using the adopted marking scheme, has proved unsuccessful with this class despite several attempts at its implementation. Analysis of the consistency of marks from these trials has shown that students generally lack sufficient maturity at third-year level. They tend to mark their friends very highly, and mark other class members erratically. There seems to be a distinct change in maturity in final year, where peer assessment has been a regular feature of oral presentations in design for several years.

The following criteria and marks (maximum 100%, of 15 marks) are used for assessing the written report:

General appearance/professionalism	5
Title page	5
Table of contents	5
Figures and tables	5
Section headings and subheadings	5
References in appropriate format	10
Citations and acknowledgements	10
Informative summary	10
Introduction	10
Conclusions	10
Development of content	25

It should be noted that all assessment allocations are in multiples of 5 marks each. Assessors quickly get a good ‘feel’ for the award of marks in these blocks. In any case, it makes little sense in sub-dividing the blocks further since the total maximum mark available for this element is only 15.

Engineering design projects

In second semester, students work on their major design project as previously described. The marks breakdown for this element of the course is as follows:

Contribution to ‘client’ meetings	20
Oral presentation	20
Written report	60

Oral presentations are marked using the scheme presented as Table 2, above. As a general rule, each project group presents a single report. The 60

Table 2. Marking scheme for oral presentations

Presentation skills	Poor	Fair	Good	V. Good	Perfect
Effective Introduction					
Introduced speaker(s)?	1	2	3	4	5
Objectives clear?					
Main points outlined?					
Preparation					
Was there a logical structure?	1	2	3	4	5
Best use made of time available?					
Level of professionalism?					
Speech and interest					
Good delivery, no annoying mannerisms?	1	2	3	4	5
Fluent, enthusiastic?					
Ability to hold audience interest?					
Content					
Knowledge of subject					
Main points emphasised?	1	2	3	4	5
Comprehension of material?					
Summaries used?					
Discussion Handling					
Were questions cleared up?	1	2	3	4	5
Were questions avoided?					
Was closing statement effective?					
				Total (max. 25)	

marks available for the written report are further broken down (as a percentage) as follows:

Presentation (layout, references, etc.)	10
Comprehension of topic, analysis & application of same	20
Interpretation, synthesis and organisation of information	20
Evaluation & judgement base, objectivity	20
Content	30

Unlike the first semester, emphasis in the second semester is placed more on how the student has developed and delivered on the design theme. Presentation skills, though important, are of less significance—students are expected to have learned these skills from the earlier module.

As an aside, the author assisted in the compilation of a marking scheme for the assessment of oral presentations in the Geology Department in Galway. The scheme is presented in Table 3.

This scheme features a binary measure of performance (students score either a zero or a 10 depending on whether they have done the required reading or not); it also features a score of zero for an unacceptable performance under each heading. Feedback on its implementation was very positive.

To return to the marking schemes adopted for Engineering Design. There are two aspects that require more detailed explanation. The marks for 'content' are allocated in a specific manner, and four areas have been identified for these marks:

- significant information retrieval and evaluation;
- significant or complex computing element;
- significant or complex laboratory or modelling element;
- significant mathematical element.

In brief, the marks for 'content' are awarded for conceptually difficult or otherwise time-consuming aspects of the design activity. Based on experience to date, even the most able students can cover no more than three of these areas in the time available. The 30% of marks, therefore, are used to top-up from 70% (the bottom end of the first class honours grade) to 100% depending on the presence of 3 out of 4 content areas and the difficulty of each one. Two independent assessment variables are addressed by this mechanism: the award of high first class honours marks (some examiners are loathe to award 90%+) and the intellectual and/or time commitment of the students themselves.

Secondly, there are 20 marks available for student performance during 'client' meetings. As mentioned above, each pair of student 'consultants' is free to make an appointment to discuss their design project with their 'client' when they so wish. These 20 marks are made available for the assessment of student interest and involvement in the project, for professional and considerate behaviour, and for honesty.

FINAL REMARKS AND CONCLUSIONS

On several counts, the assessment methods described above seem to be quite effective. On a practical level, the adopted marking schemes are relatively simple to use, particularly the oral marking scheme. They also have the advantage of transparency, i.e. students know what is expected of them, and the schemes are there to be discussed by the course director, assessors, students, and external examiners. Although the marking schemes are generally seen to fit their purpose, some outstanding questions remain to be answered. In particular, some time needs to be directed at finding a solution to the problem posed by the assessment of projects with significant differences in content.

A feature of projects in design and, indeed, projects undertaken in outside organisations is that there is a wide variation in the availability of relevant reference material, sources of expertise and advice, technical and/or practical content, and the degree of assistance provided by the host organisations (if any). In an attempt to address these difficulties, the author has used a top-up mechanism based on the perceived technical content and/or time consuming aspects of the design activity.

This top-up mechanism has been criticised for the fact that it marks each project in a different and unpredictable manner. 'Easy' projects, it is argued, have fewer marks available to them. There is no simple answer to such comments; one needs to look elsewhere for possible solutions. Without question, it is unfair (on students) to mark 'easy' and 'hard' projects in the same manner. Yet there

Table 3. Marking scheme for oral presentations—Geology

	Abysmal	Poor	Fair	Good	V. Good	Perfect
Presentation Skills						
Introduction/informativeness	0	2	4	6	8	10
Structure	0	2	4	6	8	10
Content						
Relevance of material to topic	0	4	8	12	16	20
Depth of research	0	binary	binary	binary	binary	10
Comprehension						
Grasp of content	0	6	12	18	24	30
Response to questions	0	4	8	12	16	20
					Total	

is no practical mechanism of ensuring that open-ended projects can have the same difficulty. A currently fashionable approach to this type of issue is to suggest a detailed specification of learning objectives, or outcomes, of such project-based learning. On a practical level, this approach tends to lead to a specification of competencies which students are expected to use in a variety of settings. The approach is derived from the behavioural objectives movement and the workplace [2].

There are many issues of assessment that cannot be addressed adequately in a single paper of this size. Some attempt has been made to describe mechanisms that have been adopted to ensure reliability and consistency between and within assessors. Contracted service providers have been employed both to instruct and examine in specific areas. However, it would be difficult to support the observation of reliability and consistency with any meaningful statistical evidence. In the first place, the number of projects undertaken in any particular year is fairly small and thus the statistical integrity of the evaluation would be questionable. A reasonable response might be to suggest a widening of the data to include all past projects. Unfortunately, it would be rather misleading to re-evaluate projects undertaken over the past ten years simply because the undergraduate curriculum has changed appreciably to accommodate advances in technology.

There are also issues to be discussed related to underlying but unspecified value judgements that underpin any assessment process. In heavily technical subjects, formal teaching and examination methods tend to concentrate on memory recall, manipulation, and analysis. As a consequence, a teacher who does so through solely formal methods makes a value judgement in regard to the type of material that will be taught. Indeed, it may be stated explicitly that assessment methods define what can be learned.

REFERENCES

1. N. J. Entwistle, *Styles of Learning and Teaching*, 2nd edn, Wiley, Chichester, (1987)
2. G. Brown, J. Bull and M. Pendlebury, *Assessing Student Learning in Higher Education*, Routledge, London, (1997)
3. E. de Bono, *Teaching Thinking*, Penguin Books, London, (1978)
4. A. Bloom, *The Closing of the American Mind*, Simon & Schuster, New York, (1987)
5. F. Kjersdam and S. Enemark, *The Aalborg Experiment, Project Innovation in University Education*, Aalborg University Press, Aalborg, (1994)
6. R. B. Clarke and B. Mcclelland, Teamwork at the chalkface—an integrative approach to technology and design, *Int. J. Eng. Educ.*, **15,** 2 (1999).
7. I. S. Gibson, Teaching design in manufacturing, *Proc. 8th. Conf. Irish Manufacturing Committee (IMC-8)*, University of Ulster, Jordanstown (1991) pp. 133–147.
8. I. S. Gibson, A definition of design, *Engineering Designer*, **19**, 4 (1993) pp. 26–27.
9. I. S. Gibson, A synthesized approach to design education, *Proc. 10th. Conf. Irish Manufacturing Committee (IMC-10)*, University College, Galway (1993) pp. 1192–1203.
10. I. S. Gibson, Teaching design through project management, *Int. J. Eng. Educ.*, **9** (1993) pp. 143–147.
11. I. S. Gibson, Professional development and education in engineering design, *Int. J. Eng. Educ.*, **11** (1995) pp. 93–97.
12. A. Keane and I. S. Gibson, Development and assessment of a combined communications/design course in engineering education, *Europ. J. Eng. Educ.*, **22**, 3 (1997) pp. 93–96.
13. J. W. Davies, *Communication for Engineering Students*, Longman, London, (1996)
14. L. S. Gibson, Assessment criteria for undergraduate project work in engineering design, *Europ. J. Eng. Educ.*, **23**, 3, pp. 389–395 (1998).

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