*Global J. of Engng. Educ., Vol.7, No.1*
*Published in Australia*



# Industry and the Engineering Student: a Marriage Made in Heaven?*

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Engineering can be one of the most rewarding careers available to graduates, requiring continued problem solving and the application of theory learned at university. Despite this, many engineering courses fail to make use of the opportunities available through student-industry interaction. The School of Engineering at the University of Durham, Durham, England, UK, has developed a number of teaching methods within two of its fourth year streams. All the methods rely on continued and extensive industrial contact and are beneficial, not only for the student, but also for the industrial partners. The article is an investigation into the teaching methods used, including the methodology, and a consideration of the benefits for students. It article goes on to see how the work done by students within the methodology is perceived by the industrial contacts. It is concluded that, through these methods, the University of Durham has indeed been able to provide an *arranged marriage* between students and companies and that this marriage could further be considered as being *made in heaven*.

## INTRODUCTION

The four-year MEng at the University of Durham, Durham, England, UK, offers a number of final year streams. Traditional subjects, such as mechanical and civil engineering, sit alongside aeronautics and the less conventional *Manufacturing Engineering with Management* (MEM) and *Integrated Electrical/ Mechanical Engineering* (IEME) courses.

In this respect, the word *unconventional* describes the methods that are used in the teaching rather than the subject being taught. Indeed, the IEME course is based around wholly conventional subject matter, such as stress analysis, dynamics and vibrations and so on. However, it also includes a module entitled *Advanced Engineering Design* where a number of design techniques, particularly relevant to the manufacturing industry, are investigated.

Both the MEM and Design courses are run by the staff of the Centre for Industrial Automation and Manufacture (CIAM) within the School. It is the extent of the links between CIAM and local industry that has allowed the successful development of the student-industry relationship – the main characteristic of the MEM and IEME courses and the subject of this article.

## TEACHING METHODS

A number of different teaching methods have been developed that are particularly suited to these two courses. The underlying structure of each method is fairly similar. Firstly, the students are given lecture-based classes, describing and defining a number of design or manufacturing methodologies or *tools*, which can be used in a manufacturing context to improve a company's performance. Such tools can include, for example, *Design for Assembly* (where manufacturing costs can be considerably reduced by speeding up the

*A revised and expanded version of a keynote address presented at the 3rd *Global Congress on Engineering Education*, held in Glasgow, Scotland, UK, from 30 June to 5 July 2002. This paper was awarded the UICEE gold award (joint third grade with one other paper) by popular vote of Congress participants for the most significant contribution to the field of engineering education.

manual assembly time of components), *Design for Manufacture* (simplifying component features to enable simpler and cheaper component manufacture) or *Quality Improvement Methods* (methods to significantly reduce the waste of time and money through sub-standard goods).

Some of these tools, and the *hands-on*, team-based approach they promote, have been further described in published literature [1][2]. The students then try out the tools within the classroom. For example, a breast pump may be investigated in *Design for Assembly* and different designs/models of pumps may be available for the students to analyse. Finally, and perhaps most importantly, each of these methods requires the students to interact with an industrial partner. The extent of this interaction depends on the particular method involved, but the results, ie the work and ideas of the students, can produce numerous benefits for the company.

There are three main methods of this type that require a *marriage* between an industrial partner and the students: *Industrial Problem Solving*, *Investigative Projects* and *Teaching Days*. In all three of these methods, the selection of the industrial component of the teaching methodology is only made a few days prior to the course taking place. This ensures that the project has maximum relevance both to students and to the company.

At the end of the third year, students who intend to go on to the 4h year IEME or MEM streams must take part in the *Industrial Problem Solving* course. This is a two-week course divided up into a week's training at the University and a week applying that training within a company. The immediate and primary aim of the fortnight, according to Dr Ian Carpenter, lecturer for two of the core modules in the MEM course, is to provide *preparatory training for the more detailed problem solving* that takes place in the Investigative Projects they will be required to do in their 4th year.

Prior to going into a company, students acquire a number of *tools* that may be used to tackle the problem set by the company. As such, the training in the first week covers a number of different design and/or manufacturing methodologies, any one of which may be particularly relevant to the company's problem.

After the training is completed, students are directed into randomly chosen pairs to the appropriate companies where they are introduced to the company contact. After an initial *settling in* period, the only further university contact (although the tutor is available at all times should any problems arise) is a midway check that the students are progressing appropriately with the project.

Within the company, it is the company contact, rather than the university tutor, who introduces the problem and from this point on, students are expected to work within the company as, effectively, a member of the company. Thus, working hours, dress, ethics and so on are as per the company's employees, causing minimum disruption to the company, as well as giving students a limited amount of work experience.

The *two-person* approach to the company project has been found, through several years of running such projects, to be very important. A single person would be likely to feel extremely isolated attempting a problem-solving project within a company. In dealing with the isolation, it is further likely that the student would demand more and more time from company employees and/or the university tutor, either to remove the feeling of isolation or to enable the project to progress. Having two students in groups allows them to support each other throughout the project, bounce ideas backwards and forwards between themselves and progress the project at an appropriate speed.

On the other hand, groups with more than two people have been found to cause a number of problems, including isolation of a single member and a lack of effective use of teamworking. Indeed, groups of three students working on a project have not been found to deliver any more than a group of two and each student has appeared to gain less benefit from the project than would be expected in a two person group.

The end of the project is marked by the *road-show*. Each pair of students presents the outcome of their project to the other students doing the course and to appropriate members of the company. Through this method, students gain an appreciation of what the project has taught other companies and students, on top of gaining an insight into the type of work in another Northeastern company. Further feedback is available to the company through a formal project report, capturing the salient details from the project and allowing a little more depth than is possible in the road-show presentations.

The two-week *Investigative Projects* are perhaps the core of the final year for the manufacturing and integrated engineering students. They are similar in style to the projects in the industrial problem-solving course – students are teamed into pairs to approach a problem being faced by a local company at that point in time. As the projects take place at the end of the terms, they build directly on the lecture material. The increased duration gives a more realistic and more in-depth approach to the project than is available during industrial problem solving and it would therefore be expected that both students and companies get considerably more out of these projects.

As with the industrial problem solving courses, the investigative projects are part of the examination procedure. The final reports are examined, as are the project presentations. Both the reports and the presentations are significantly different from those required within a normal final year project. They are directed at senior management within the companies and are therefore intended to be done in a professional format, rather than the academic format required in the final year project.

The *Teaching Days* are single days throughout the year, where students spend the entire day within a company. This company has been specifically selected to highlight a particular part of the course. There is usually a brief presentation by the host company, firstly introducing the type of work in which they are involved and secondly demonstrating how they make use of the manufacturing/design tool or method that is the day's topic. The majority of the day is then spent using the tool to tackle a problem contemporary to the company and the results are presented back to the company at the end of the day.

## THEORY

The ultimate aim for an engineering lecturer is to enthuse the students sufficiently so that they take up engineering themselves. Traditional engineering courses that are lecture- and theory-based typically have to provide this kind of encouragement through the lecture format or, to a limited extent, through a final year project. However, where students are able to see the reality of engineering and the application of their knowledge to real engineering problems, the enthusiasm can more easily be generated. In this way, the definition of the learning outcome begins to broaden. The aim becomes not only enthusiasm for engineering, but also an appreciation of everyday engineering and its issues, such as how industrial organisations work and the different cultures they can embrace.

Professor Sir Graham Hills, in his keynote address to the *3rd Global Congress on Engineering Education*, held in Glasgow, Scotland, UK, describes two kinds of knowledge: *explicit* (or codified) and *tacit* [3]. Explicit knowledge is *the vast accumulation of knowledge as facts, theories, illustration, films, simulations, etc* which can be *taught, learned, remembered and re-expressed* with exactitude [Hills' own emphasis] [3]. In the context of the teaching methodologies described here, the explicit knowledge is provided through the lecture courses or seminars. This knowledge is then drawn on by the students when working within the company to enable them to carry out their projects.

Tacit knowledge, on the other hand, is *the collection of knowledge that cannot yet be or has not yet been written down or recorded. It is the knowledge of experience that cannot be acquired from books and from lecture notes. It cannot be taught; it can only be learned* [3]. By ensuring that the students spend time within an industrial environment in all three teaching methods, the students are directly provided with the opportunity to gain Hills' tacit experience – experience that he claims *is always more important than codified knowledge* [3]. Consequent learning outcomes are therefore likely to include everyday skills, such as problem solving, *inventiveness*, communication, understanding and the ability to deal with shop floor-management type issues, writing of professional project reports, presentation skills and so on. In short, while attempting to show the engineering reality of lecture-based theory, the overall learning outcomes encompass any number of the real-life engineering issues, achieving the aim expressed earlier in this section.

If the 4th year manufacturing and integrated courses are to provide these learning outcomes within the overall context of a learning environment, particular care must be taken to ensure *constructive alignment*, where *constructive alignment* is taken to mean that *the curriculum aims and objectives, the teaching methods, and the assessment all address the same thing* [4]. In this context, the *curriculum aims and objectives* are to prepare students for the world they will eventually occupy: that of the professional engineer. The teaching methods and assessment must therefore reflect this, and indeed they do. The application of theoretical knowledge within the industrial environment, as evidenced in all three teaching methods, combined with the requirement for the final reports and presentations to be aimed at the professional engineering community, ensures that the courses are fully *constructively aligned*.

Such an approach clearly fits in with Laurillard's *conversational framework* [5]. In describing her framework, Laurillard suggests that *the learning process operates on the two levels of discussion of theory and experienced practice, linked by processes of adaptation and reflection*. The combination of theory and practice provided within the three methods described above, together with the opportunities for feedback – between students, teachers, shop-floor workers and managers – allows the *processes of adaptation and reflection* to develop freely, ensuring the maximum possible benefit to all those involved in the process.

## ASSESSMENT

Given the anticipated learning outcomes outlined above, ensuring that the assessment procedure is fully aligned with curriculum aims and teaching methods is of prime importance. Of the three teaching methods considered in this article, only the teaching days are not *formally* assessed. However, they do provide case material that may be required for answering examination questions. The investigative projects are extremely important for the students' overall grade, as together they are taken to be one third of the final year project, and therefore around 7½% of the entire degree classification.

Consequently, the marking scheme goes beyond simply marking a report or a presentation and takes into account factors that include effort, initiative and ideas, understanding of the work and its broader perspectives and overall achievements. In order to achieve this, the examiners complete a standard pro forma. This pro forma uses headings such as those above and gives examples, under each heading, of the level of attainment that might be required for a certain grade. By consideration of such factors, the professionalism of the students within the company can be assessed effectively.

The 1992 Engineering Professors' Conference produced a *Taxonomy of Examination Styles* in which examination styles are compared *according to their potential to test levels of learning of different kinds* [6]. These levels include:

- *Knowledge*: the recall of memorised information.
- *Skills I*: objectively measurable skills such as *maths calculations, spelling and grammar, computer skills etc.*
- *Skills 2*: defined as complex *skills which require judgement by examiners - like communication skills, interpersonal skills, leadership skills, etc*.

Clearly at the level of these projects, and by marking a *project* rather than purely a report, these *complex skills* (many of which come under Hills' *tacit knowledge* heading) can be identified and the students credited within the marking scheme for demonstrating them.

## STUDENTS' VIEWS

In order to ascertain the views of students who have graduated from the MEM course (the IEME course having no graduates as yet), a questionnaire was sent around to recent graduates. A set of statements was directed to each of the three methods, with the recipient able to disagree strongly, disagree, be neutral, agree or agree strongly. The statements addressed to each method, detailed below, were identical, apart from a single statement. Note that *course* was replaced by the specific method – eg *I enjoyed the teaching days* for statement 1.

1. *I enjoyed this course*.
2. *During this course I learnt some important manufacturing principles*.
3. *Varied between teaching methods*:

    a) Industrial Problem Solving*: The course prepared me for the 4th year manufacturing course*.
    b) Investigative Project*: The projects allowed me to apply what I had learnt throughout the course*.
    c) Teaching Days*: The teaching days consolidated material I had learnt throughout the course*.

4. *The in-company part did not demonstrate any manufacturing principles*.
5. *The course was useful preparation for my current job*.
6. *The course did not help me decide what kind of job to apply for*.
7. *The course provided background theory that is useful in my job*.
8. *The course provided no material that I use in my job*.
9. *I regularly use other aspects of the course in my job (please detail below)*.
10. *The course provided little of use for my current job*.
11. *I thought the companies gained from being a part of the course*.
12. *I found that the fact that I had done this course helped me to get a job*.

A further set of statements, also requiring a response between *disagree strongly* and *agree strongly*, was directed to the students' approach to learning, and are as follows:

1. *I learnt the course material because:*

    a) *It was interesting*.
    b) *I had an examination to sit*.
    c) *I thought it would be useful preparation for a job*.

2. *In hindsight, the course was of no use to me at all.*
3. *I still remember a lot of the material from the course.*

In addition to these statements, space was available for further comments on any of the teaching methods.

The detailed responses from these questionnaires present too much information to incorporate them fully within this article. All the results presented within the text proved to be statistically significant (see Appendix 1 for a full discussion of their statistical significance) and some interesting trends can therefore be highlighted.

In particular, before considering the teaching methods, it is interesting to note the approach to learning. Figure 1 shows the results of this section of the questionnaire. Note that in this graph, as in all the graphs presented, the *positive* responses – namely *agreed* and *strongly agreed* – are aggregated into one *agreed* section, and the *negative* responses into *disagreed*.

Every graduate agreed that they had learnt the course material because it was interesting – statement 1(a) – but only 80% because they had an examination to sit – 1(b). This can be contrasted with the results of a separate questionnaire sent to all current finalists where 97% were learning the material because of the final examination, but only 57% agreed that it was interesting.

All graduates disagreed with the statement that *In hindsight, the course was of no use to me at all* – statement 2 – and nearly all agreed that they still remembered a lot of material from the course – statement 3. Clearly, the course had a profound effect on the students.

The results of the statements relating to teaching methods can be seen in Figures 2 and 3.

Before looking at the individual methods, some general trends can be highlighted. Four statements elicited very strong responses, either in agreement or disagreement, these being numbers 1, 2, 4 and 11. Thus, as well as enjoying all three teaching methods, the students felt that through these methods they had *learnt some important manufacturing principles* as (sometimes) demonstrated by the companies. Interestingly, the students also thought that the companies themselves had gained from being part of the exercise. This possibility will be investigated later in the article.

## Industrial Problem Solving

All of the respondents (100%) agreed or strongly agreed with the statement 1 and 93% with statement 2 as discussed above. In addition, 95% agreed with statement 3 - *The course prepared me for the 4th year manufacturing course*. Clearly, the course is meeting its primary aims as voiced by Dr Carpenter. This is further evidenced in supplementary comments, such as:

- *Good preparation for 4th year.*
- *Set the scene.*
- *Nice little insight into what the 4th year course would be.*

## Investigative Projects

Sixty-seven percent of respondents strongly agreed that they had enjoyed the projects, with a further 30% agreeing. Given the aim, stated earlier, to induce

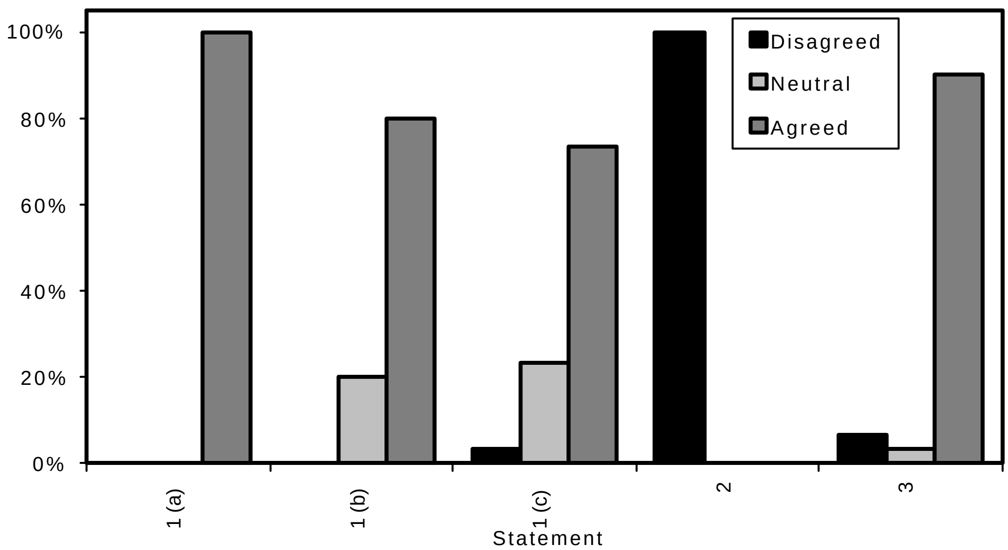


Figure 1: *Approach to learning* questionnaire results.

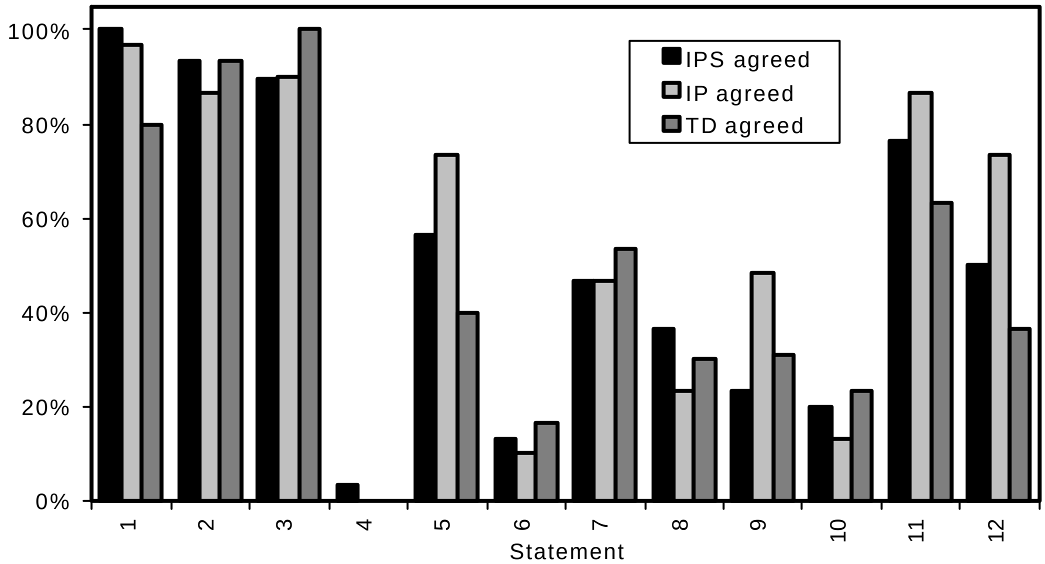


Figure 2: Percentage agreeing with each statement.

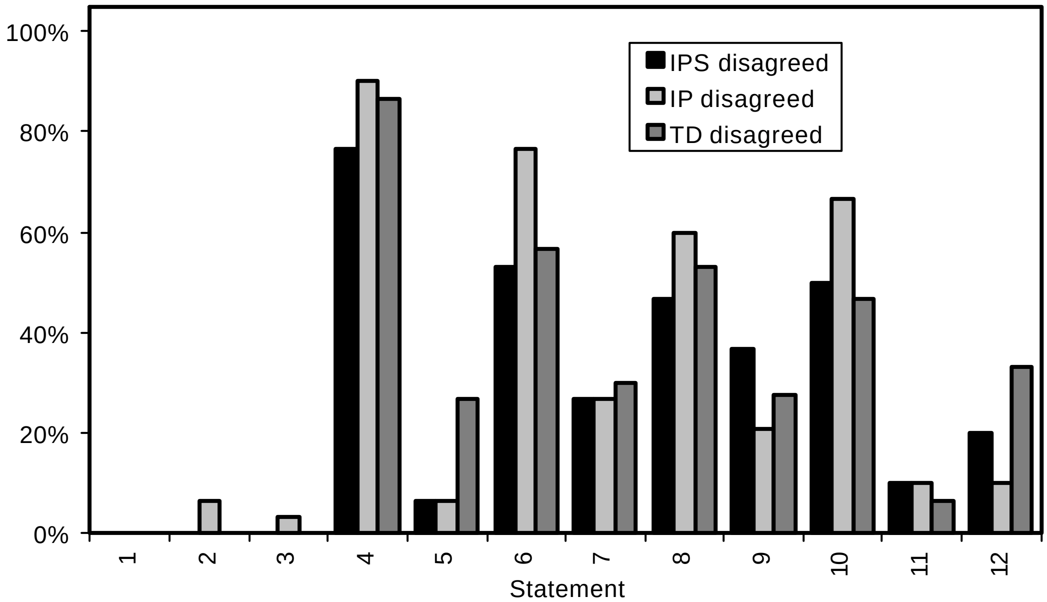


Figure 3: Percentage disagreeing with each statement.

enthusiasm in engineering, this is particularly pleasing. Of further interest is the response to statement 6 in that only 10% agreed (none of them strongly) with the statement *The projects did not help me decide what kind of job to apply for*.

Additional comments directed to the projects include: *These courses made me enthusiastic about going into manufacturing*; *brilliant, able to learn and get invaluable experience*; and, particularly, *the experience I gained in these projects is more useful to me in my current job than everything else I learnt while at Durham.* Perhaps the only major negative point that arose from the projects was the occasional absence of feedback from the company as to how they have or have not acted on the students' proposals.

## TEACHING DAYS

The results regarding Teaching Days are perhaps the most equivocal, with little standing out apart from the general trends already mentioned. That this is the case is confirmed by the fact that only half of the questions produced statistically significant results, as discussed in Appendix 1.

The additional comments offered on this method are equally contrasting, from *inspiring; it was very useful to see successful companies deploying techniques …* to *least valuable* [of the three methods]. However, one exception is that, as for the investigative projects, the teaching days seem to have helped in the choice of a job, with only 17% agreeing with statement 6.

## FURTHER BENEFITS

It is clear from the comments in the *further responses* sections of the questionnaires that many of the graduates are aware of some of the *consequent learning outcomes* detailed earlier, beyond the obvious subject-specific skills. Of particular note are the following comments from three graduates that particularly highlight the *tacit* knowledge they have gained:

- [The course] *equipped* [me] *with skills that are useful in all walks of life - transferable skills, working in teams, presenting in front of a group, working quickly and logically to meet deadlines, etc ...*
- *Negotiating skills (with shop floor + supervisors) developed then are used now. Also ability to explain a logical course of action in such a way as to engage support of others. Working practices - particularly* short + sharp *project management - were greatly developed.*
- *When I meet new people at work & mention that I read Engineering they show a great deal of respect - this is because they realise I learnt some valuable skills which are transferable such as structured problem solving, analytical analysis, etc. I, on the other hand, thought I learnt about JIT, Lean Manufacturing, etc.*

Thus, with hindsight, the students can see benefits that might not have been obvious at the time of doing the course.

Only 10% of respondents disagreed with the statement *I found that the fact that I had done this course helped me to get a job* when applied to the investigative projects. A specific example given was that the teaching methods were *v. useful* [for] *demonstrating client exposure and practical problem solving in a business environment when attending job interviews.*

## THE COMPANIES' VIEWS

While it may seem that the predominant benefit of the teaching methods would be for the students, benefit for the companies involved is crucial if their continued involvement is to be assured. Unfortunately, anecdotal evidence suggests that the type of *student in-company project* normally run by universities is often perceived to be of little value to the host companies. Therefore, in order to assess this, company feedback is sought as a matter of course for the industrial problem solving and investigative projects. The companies are asked to rate a number of project aspects on a negative-to-positive scale of 1 to 5. The results demonstrate the companies' perceptions of the attributes rather than, perhaps, an objective view. However, in terms of a benefit to the company, it is the companies' perceptions alone that are important.

The results for the investigative projects carried out in 2000 and 2001 are extremely encouraging and are statistically significant. Eighty percent of the companies gave a score of 4 or 5 for *achievement of objectives*, indicating that the project had more than met expectations. *Convincingness of feedback* and *realistic solution to problems* were awarded scores above three in 86% and 87% of projects respectively, indicating companies' trust in the results. Finally, for taking the results forward, *ability to build on recommendations* is rated as 4 or 5 for 93% of the projects. These results, presenting the views of the companies, strongly suggest that the projects are providing definite benefits to the companies.

Similar anecdotal success stories can be found within the industrial problem-solving course. A recent project involved re-designing a component to reduce labour costs during assembly. The result was so successful that the company sent the new design to its biggest American customer for trials. It is expected that the new design will save around £0.75 on each of the 50,000+ components sold each year. The cost of re-tooling to make the new component is likely to be £10,000, giving savings of £38,000 per annum, after a payback period of around three months.

Mechetronics is one company that has had a long-standing relationship with Durham University. While Jim Summerbell, the Technical Director, recognises that the students gain a lot from their projects within the company, he believes that the company actually gains more. Mechetronics is only a relatively small firm and, therefore, cannot afford to spend a lot of time *babysitting* students, as might be the case with traditional in-company projects. Instead, says Summerbell, with Durham students the majority of the time is spent in the briefing – after that they *hardly notice they're there*. Yet at the end of the project they come up with some *bloody good ideas!*

While the companies' potential benefits may be considerable, they will only be realised if it has the desire and resources to carry them forward. The rapport that has been built up between the University and local industry means that if the students suggest some improvement, the company will, on the whole, accept this.

However, the implementation of the proposal is altogether different. Corporate inertia, company politics and personnel issues – both of the companies and of the companies' customers – can hinder the execution of even the best money-saving proposal. Such an issue goes beyond the realms discussed here, but is a factor that must be realised and accepted in the development and running of any of the teaching methods.

## CONCLUSION

The 4th year MEM and IEME engineering students at the University of Durham are taught through a number of different industrial-based methods. The research outlined here shows that these methods have a considerable impact on the students – encouraging them to learn for reasons beyond their final examinations, sometimes even because the material is interesting! The benefits the students believe they have gained are considerable, both academically and in acquiring management and communication skills, based on *tacit knowledge* that cannot easily be developed through traditional lecture-based courses.

However, while the students benefit significantly from this style of teaching, the industrial partners that are involved also profit – often directly through improved components or processes. While the arranging of this marriage between industry and student is by no means easy, the results for all those concerned would suggest that it is indeed a marriage made in heaven.

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## APPENDIX 1

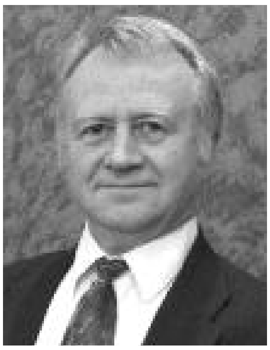
The results of the questionnaires (sample size = 30) were tested for statistical significance taking a 5% significance level on a two-tailed test. It is worth noting that, as the test is two-tailed, the effective standard against which each result is examined is actually a 2.5% significance level, providing considerable confidence in any results found to be significant. All of the results that are individually quoted within this article proved to be significant against this test and, indeed, the majority of the results passed the test. The only exceptions, of all the tests mentioned in this paper (including the questionnaires for the final year students and for the companies) were:

- Industrial Problem Solving: statements 7, 8 & 9.
- Investigative Project: statements 7 & 9.
- Teaching Days: statements 5, 7, 8, 9, 10, 12.

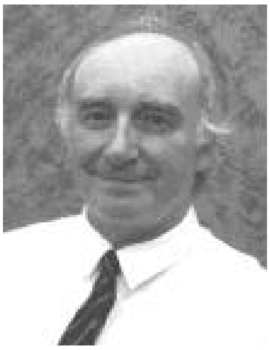
All of the other results were significant.

## BIOGRAPHIES

Dr Tim Short is a lecturer in design at the Centre for Industrial Automation and Manufacture in the School of Engineering, University of Durham. Teaching mainly in the areas of design methodologies and renewable energy systems, his major research interest is design for sustainable development, currently considering the use of appropriate technology for water provision in developing countries.



Mr John Garside is a teaching fellow and industrial tutor in the Centre for Industrial Automation and Manufacture. He spent nearly 20 years working for Philips Electronics and associated industries, mainly in industrial engineering and business improvement. He then became the Durham tutor to the unique Cambridge-based ACDMM course. Since then, he and Professor Appleton have continued to develop courses at Durham University to their current level of industrial interaction.



Professor Ernest Appleton holds the Chair in Manufacturing Systems at the University of Durham. He is Chairman of the Centre for Industrial Automation and Manufacture and Deputy Chairman in the School of Engineering. Before moving to Durham, he was a lecturer in engineering at the University of Cambridge and a Director of the Caledonian Mining Company Ltd.

His current interests are in the areas of advanced manufacturing technology and automation, a field in which he has published a number of papers and a book.

Throughout his career, he has operated at the academic-industrial interface, working with such companies as British Aerospace, IBM, Ford, etc. He also has a keen interest in transferring appropriate technology into the medium and small company sector.

## *3rd Global Congress on Engineering Education:* Congress Proceedings

edited by Zenon J. Pudlowski

This volume of Congress Proceedings is comprised of papers submitted for the *3rd Global Congress on Engineering Education*, which was held at Glasgow Caledonian University (GCU), Glasgow, Scotland, UK, between 30 June and 5 July 2002. The prime objective of this Congress was to bring together educators, professional organisations and industry leaders from around the world to continue discussions covering important issues, problems and challenges in engineering and technology education for this new millennium.

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The 3rd Global Congress could be characterised as an academically fruitful event with most papers in these Proceedings being of a very high academic standard. Furthermore, all papers have gone through a strict refereeing process to ensure their relevance for years to come.

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