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## **Application of Computational Fluid Dynamics (CFD) through project-based learning**

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## Application of Computational Fluid Dynamics (CFD) through project-based learning

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Subject Area: Computational Fluid Dynamics

This case study has been developed from data gathered through observations of the teaching component; interviews with the tutor and a student focus group.

### Background

A Computational Fluid Dynamics (CFD) module was started in the 1990s when many colleagues perceived CFD as too 'dangerous' to be taught at undergraduate level. It was usually reserved for postgraduate level study. The tutor, Henk Versteeg, and the department could see the commercial applications of the codes and wanted to introduce the students to some of the software that was being developed. Henk approached the software vendors directly and negotiated educational discounts for the licences.

Initially, the approach focused on the engineering science but over time Henk wanted to bring in a more application-oriented approach and, as the codes became more sophisticated, this became more realistic. The original exercises were purely academic but about ten years ago they decided to bring in industry, through initial links provided by other colleagues within the School. The first company approached was Perkins because of strong existing links, in particular through a Royal Academy of Engineering Visiting Professor. There are now three companies involved in the *Computational Fluid Dynamics 2 - design projects* module and these use the module to experiment with projects that they either cannot prioritise at the time or that they would welcome fresh minds to investigate.

The students are given a programme of skills training and then work in self-selected groups on 'live' industrial problems in a simulated consultancy environment. Senior engineers from the partner companies formulate the industrial needs and supply information, while the academic tutors ensure that the objectives are feasible and act as facilitators of student learning of additional task-focused CFD skills. The main group activity consists of taking on board the industrial problem, turning it into a model that is amenable to solution with a commercial CFD code and working out the technical details required to produce an initial solution. When this has been completed, each student works on a more refined solution, performing an individual investigation of a detail of the industrial problem. Students submit group and individual CFD simulations for assessment, as well as a report on their findings. The final event of the course is a presentation of the findings at the industrial company premises. This adds a new communication dimension, including possibly having to communicate their ideas to a non-CFD specialist.

Before they take this fourth year module, the students have studied a CFD module in year three. CFD 1 provides an introduction to coding and CFD 2 is more about exploring what can be done with the codes. The assessment is based on the developmental aspects of their work, rather than responding to constrained parameters within an examination. The project approach helps students to develop different skills and approaches to problem solving than may be gained from following instructions in a tutorial.

The project is introduced in week two of the module and is 'pitched' by the companies. Ultimately, there is both individual and group assessment. The students develop a basic model as a team, then assign

individual tasks. They need to submit an account of both parts. Each project is configured in such a way that the students will need to develop a skill not previously taught. Tutors negotiate with the participating companies to achieve realistic outputs from the students.

The students are timetabled from 2 – 6pm on Friday afternoons. There are two adjoining rooms available for them to meet. One is equipped with computers and the relevant software, the other is a larger flat room used for whole class presentations, meetings with tutors and group meetings.

Representatives of the companies supporting projects are invited to attend some of the sessions during the semester. The industry tutors meet initially with all students working on their particular projects. They provide an overview of the company and offer further details about the primary goals for the projects and desirable outcomes. This provides the students with the opportunity to ask questions about the technical details of the design brief and seek clarification of the data sets already supplied. The student groups often prepare well for the meetings, including drawing-up a list of queries common to all groups tackling the brief to maximise the use of the time available with the tutors.

The industry tutors also meet with individual groups and discuss the ideas generated to date, offering suggestions and feedback on taking the work forward. The academic tutors are also available during all of the timetabled slots and move around the groups answering queries and offering feedback on progress.

### **Reasons for introducing this teaching method**

It was felt that experiential, industry-focused projects enhances students' motivation to learn. Henk has experience in industrial consultancy and knew that this was a good environment for rapid learning. Henk wanted to place fourth year CFD students into such an environment with the ultimate aim of giving them confidence, through successful project completion, and achieve high levels of self-learning and discipline.

### **Lecturer perspective**

Henk maintains that the course receives consistently high student satisfaction levels in module feedback ratings and also from direct anecdotal student comments. On this module, he feels the student performance levels generally range from good to outstanding and that the work produced is of a very high standard. As a consequence, the course has been received very enthusiastically by the industrial partners and one of them - JCB - has instituted an annual Computational Fluid Dynamics Prize to recognise outstanding student performance on this module.

### **Students' perspective**

All of the students in the focus group had been on an industrial placement year so they were now quite mature students, being in the fifth year of their degree programme. The majority felt that they would be going on to an industrial career. The design projects module followed on from a pre-requisite CFD module, described as being quite different. It developed the background theory and an understanding of the equations that the programs are based upon. At that time the students were only working at the 2D level and learning the basics of the code. Essentially, they were using an earlier version of the software and for the design projects they have had to step up to using much more complex software and work in 3D. The students felt that they were being "*dropped in at the deep end*" and that there was a very steep learning curve, even for the student who had some work experience using CFD in industry. The students realised that they would have had to negotiate the same learning curve if they had gone straight into industry but without the support from Henk.

In CFD2 there were real industrial problems that required solutions: *“Whenever you wanted to know what the company wanted, you didn’t speak to Henk, you e-mailed the company.”* The students said that having a real industrial problem sets this module apart from some other modules and that they appreciated the amount of work that Henk had done to secure the projects. The projects made the students focus on what outputs the industry would want, rather than any outputs that could be generated. They felt it stimulated their interest to be working on projects that the companies wanted done when compared to the situation in some other courses where they were given what one student described as *“meaningless”* projects just for the sake of doing projects and that this did not stimulate interest at all, it was *“mind-numbing”*!

They thought that having to think about how to solve the problem, conduct the project and make presentations was as close to the industrial project process as one could get. They also learned that the projects were definitely ‘open-ended’ and that pre-conceived notions, on both sides, sometimes had to be reconsidered. They found that receiving good feedback from the companies at the end was very rewarding: *“They thought that the work we had done was valuable and it had saved them a lot of money.”* Essentially, the student groups did indeed feel that they were acting like a consultancy and, conversely, that it was a cost effective process for the companies.

Students were divided over the merits of the early part of the module, where there were two pieces of coursework: one basic and the other a mini project. Some could see the pedagogical reasoning and felt that the process got them thinking about CFD and gave them confidence in doing project work to tight time limits, while others thought that more tutorials on using the more complex aspects of the software would have been more beneficial in practical terms.

In terms of the time constraints within the industrial projects, Henk was very supportive of the students. He made it clear to them that, fundamentally they were working to complete a University module and if there were issues, with for instance company data, he would step in and say that they needed to get the work completed and that they would have to make assumptions or simplify the data to be able to do so. Apparently, interpreting results is one of the most difficult aspects of CFD. In trying to do this, Henk would help the students, but not by telling them the answer: *“He’s very subtle how he does it. He will just say ‘Really’ and that means, actually you need to go and look at that.”* They knew that Henk had provided them with the theory in CFD1 and now he was getting them to think for themselves and boost their self confidence.

The students strongly believed that Henk knew the extent of individual contributions to the group projects. They felt there was no need for peer assessment, as they were confident that Henk’s assessments would be absolutely fair. They also felt that they were at a level where everyone knew what needed to be done and would get on and do it, for their own benefit and also for the group. This was particularly so as the groups were self selected and therefore composed of friends.

For the reporting, there were reports of the group work and individual’s reports of their own sub-project. One student proposed that there should only be a single report from each group that reviews the overall problem, collates the individual sub-reports, presents the main findings and conclusions and finishes with the recommendations for the company. This would be more in line with a consultant’s report, yet still would reflect the individual contributions. There was significant support for this view. This would have the benefit of maintaining the teams through the project, whereas in the current set up the teams could fragment into the individual sub-projects, with no real team cohesion.

## Issues

Each group made their presentations at their project company, so the other groups didn't witness and learn from them, which could have added value to the experience, although there was a lot of inter group discussion throughout the module. A visit to the companies at the start of the year could also have been beneficial as this may have prevented some misconceptions that were not detected until later in the year and required some initial work to be redone. However, some company locations were an issue, with one being located on the other side of London.

There was also an issue with a company's level of prior experience in CFD. Companies that were essentially new to CFD posed limitations for those students on the module. There was a need to simplify things to be able to run the project within the timeframe. The company has now learnt about the process and, it is hoped, will provide valuable and possibly more complex projects in future years. For other projects the complexity of the computations means significant time is need to run them (e.g. 16 – 20 hours), a resource implication for others who may wish to adopt this approach.

## Benefits

The students were very positive about 'learning by doing' being very effective: *"It is not a 'learn and forget' type of module."* They gained confidence and felt proficient in using commercial CFD code. A grounding and experience in CFD is considered to be a valuable addition to a CV.

The industrial project was seen as being as close to real life as possible and, therefore, a realistic preparation for an industrial career using CFD. The format of the projects also allowed both the students and the companies to obtain valuable insights into how the other would tackle the same problem.

## Reflections

In comparison with other modules on their degree course, the students considered this to be one of the hardest but, at the same time, they all found it one of the best learning experiences and the most rewarding: *"In terms of getting something out of it, probably it was the best!"* There were the additional benefits of gaining a clear understanding of industrially-orientated project management and significant professional development.

Each group, as they were involved with different companies and working on different projects, could be learning different specific single areas of CFD. Another related aspect was that the different projects could be of quite different levels of complexity and this needs to be managed and coordinated carefully. Henk saw these differences as also adding to the realism of the exercise, providing students with a supportive environment in which to develop their confidence in learning new things from each individual activity in which they were engaged.

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