Teaching of Thermodynamics and Fluid Mechanics using Interactive Learning Methods in Large Classes

W. Dempster, C.K. Lee, J.T. Boyle

Dept. of Mechanical Engineering
University of Strathclyde
Glasgow, UK

Abstract
In this paper the successful implementation of interactive learning techniques to the teaching of large classes is discussed. It is believed that a number of factors, including the use of peer instruction, classroom communications systems and a team teaching approach has led to the success of the techniques. The practical implementation of the technique is presented for the difficult topic of Thermodynamic and Fluid Mechanics.

1 Introduction
The teaching of Thermodynamics and Fluid Mechanics has traditionally been perceived by students to be a difficult and challenging topic within engineering courses. This often results in poor motivation and performance by students and dissatisfaction by teaching staff. It is often the case that learning is superficial and even students in the final years of a course are still struggling with concepts and techniques taught in earlier years. The difficulties with learning Thermodynamics and Fluid Mechanics are apparent to most academics themselves: it is rich in concepts and confusing in vocabulary; it usually requires application of more than one basic principle and multiple constitutive equations to analyse any given problem, resulting in confusion as to how these equations interact. It should also be remembered that difficulties in unraveling the Thermo-Fluid Sciences are not restricted to novices. Historically the science of Thermodynamics and Fluid Mechanics was not fully resolved until the 19th century while the basis of the sister science of Newtonian Mechanics was effectively resolved by the 17th century. Also, students are exposed to formal Mechanics teaching but more limited Thermodynamics in their pre-university education, resulting in a more formidable challenge since the knowledge gained in Mechanics classes are not immediately useful in Thermodynamic and Fluid Mechanic classes. Traditionally, Thermodynamics and Fluid Mechanics has been taught through a combination of lectures, problem solving tutorials and laboratory based practicals. However, it has long been known, (Bligh, 1971) that the lecture mode of teaching has severe limitations when it consists of a passive learning environment. Alternatively, learning environments that include opportunities for dialogue and discussion and challenge a student’s understanding also enhance a deeper understanding and increase student motivation. There are a number of techniques that have been discussed in the literature which provide this environment: Peer Instruction, (Mazur 1997), Active Learning, (Leonard et.al, 1999). One of the main difficulties of applying these techniques is the large numbers of students that exist in university taught classes and the wish to create a dialogue between instructor and student and between students. Over the last few years, a number of approaches have been developed to enhance the teaching of physics. In particular, the
developments of the Physics Education Research Group (PERG) at the University of Massachusetts (Gerace et al., 1999) and the work of Mazur at Harvard has shown how the combination of an electronic classroom communication system and learning methodology involving a series of questions and feedback can enhance understanding and motivation in large classes.

By building on the developments in the US, the Mechanical Engineering Department at the University of Strathclyde (UK) has for the past 4 years been exploring the use of interactive teaching techniques. The implementation of the techniques was introduced over a significant number of classes within the Department of Mechanical Engineering and in a relatively formal manner. The difficulties associated with the teaching and learning of Thermodynamics and Fluid Mechanics was regarded as a good challenge for the techniques. The initiative has been regarded as successful and this was believed to be due to a combination of factors related to practical implementation of the techniques. It is therefore the purpose of this paper to illustrate how the techniques were implemented and indicate the reasons for its success. First we will describe the class content and requirements. Next we will describe the teaching methodology and the physical environment to provide an enhanced learning environment. Finally, we will present statistics to indicate the improved learning outcomes and what has been learned regarding the teaching of Thermodynamics and Fluid Mechanics.

### 16177 Thermodynamics and Fluid Mechanics

This class is an introduction to Thermodynamics and Fluid Mechanics and is the first of a series of three in the Mechanical Engineering course (1 per year) before more specialized classes in Thermo-Fluids. The class is also taught to Naval Architects, Electrical-Mechanical and Manufacturing engineering students. It consists of 48 hours of teaching time and contributes 1 credit to a 12-credit syllabus in the first year. The content of the class is shown in Table 1 and is supported by the text *Thermo-Fluid Sciences* by Cengel and Turner (2001).

<table>
<thead>
<tr>
<th>Topic</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Terminology and concepts</td>
<td>2</td>
</tr>
<tr>
<td>2 Units and dimensions</td>
<td>2</td>
</tr>
<tr>
<td>3 Energy, Work and Heat</td>
<td>6</td>
</tr>
<tr>
<td>4 First Law of Thermodynamics closed systems</td>
<td>6</td>
</tr>
<tr>
<td>5 High grade- low grade energy concepts</td>
<td>2</td>
</tr>
<tr>
<td>6 First law of Thermodynamics (control volume) SFEE</td>
<td>2</td>
</tr>
<tr>
<td>7 Property relationships for a perfect gas</td>
<td>2</td>
</tr>
<tr>
<td>8 Thermodynamic processes</td>
<td>6</td>
</tr>
<tr>
<td>9 Fluid mechanic concepts (streamlines)</td>
<td>2</td>
</tr>
<tr>
<td>10 Continuity equation</td>
<td>2</td>
</tr>
<tr>
<td>11 General Energy equation for incompressible flow</td>
<td>2</td>
</tr>
<tr>
<td>12 Energy equation for frictionless flow -Bernoulli’s equation</td>
<td>4</td>
</tr>
<tr>
<td>13 Energy equation with friction</td>
<td>2</td>
</tr>
<tr>
<td>14 Energy equation with friction and work</td>
<td>2</td>
</tr>
<tr>
<td>15 SFEE including thermodynamic Processes</td>
<td>6</td>
</tr>
</tbody>
</table>

**Table 1  16177 Thermodynamics and Fluid Mechanics class syllabus**
2 Teaching Methodology

The basic premise is that students should be continually engaged during the lecture periods and participating actively in the learning process. Recent research suggests that knowledge is constructed by the learner through a process of being challenged and self-appraisal, (Leonard et al., 1999). How this has been implemented depends on what the particular learning objective is. For example, in the introductory Thermodynamics element of the class, effort is given to understanding terminology, the importance of units and dimensions, Thermodynamic concepts, basic Thermodynamics principles, mathematical representations of the basic principles, calculation techniques and finally the application in a context appropriate for the student cohort, (in this case mechanical engineers). The learning objectives have been classified into two separate categories: (i) knowledge that can be described as factual, or reduced to a small element. Examples of this would be terminology, basic principles or concepts. (ii) A second category is identified which considers knowledge that is essentially procedural. Examples of this are calculation techniques and equation manipulation. The learning process can be illustrated using a learning cycle description and is indicated in Figure 1.

![Learning cycle diagram for 16177](image)

The activities that are carried out in the classroom involve more interaction with the student than previously occurred with a standard lecture. There is therefore much less time devoted to lecturing the material in class notes or in the prescribed text book and more time devoted to investigating or challenging the students’ understanding. This method now requires the students to prepare themselves prior to attending the teaching session. This in itself is not without its difficulties. However, if the reading requirement is kept to a realistic level (2 or 3 pages max.) then it can be reasonably successful. Each teaching session begins with a short presentation to summarize the key elements to be discussed or to emphasize or clarify aspects that are difficult to appreciate from reading. After this, the students are given a task which explores their understanding of the topic and challenges their current state of knowledge. This therefore assumes that one knows what their current abilities are. Alternatively, questions of
increasing difficulty can be asked to identify where the students’ difficulties are. The tasks either take the form of multiple choice questions or a series of calculation based tasks. The students are at liberty to collaborate in groups to obtain an answer. The peer instruction nature of the learning is deliberate and a positive contribution to the learning process. At the end of the working period the students respond with an answer. The variations in responses can be recorded and then presented to the class as a whole. At this point the instructor, depending on the level of correct responses, would discuss the correct answer. An important feature is closure of the session and review. This is achieved both by teacher-centered discussions in class and by making available the tasks and solutions via the Internet after the session is completed.

There are several features of this approach that lead to a constructive learning environment. (i) The student’s knowledge is being challenged at a pace that provides the opportunity to think and to discuss the problem with peers. (ii) The student is now more actively involved in using the information he/she is presented with and constructing an understanding of it. (iii) The instructor also provides a reference for the correct answer and the students are more attuned to the answer from having thought about it. (iv) The students are more motivated, mainly because they can witness immediate progress in their understanding and more enjoyable than a one-way dialogue in the traditional lecture format.

It must be noted that the interactive learning methodology is not new and has been advocated in various forms in the literature. The problem arises in practice when transferring it to large class sizes. In the current application the success of applying such a technique has relied much on a number of enabling features. These include (i) arrangement of students into formal groups to allow for peer instruction (ii) the availability of a classroom communication system and (iii) a team teaching approach and finally (iv) willingness for Departmental resources to be invested in staff development and training. Each of these points are discussed more fully below.

Peer Instruction. To provide a less threatening atmosphere and to encourage the formation of a cohesive learning environment, the class is split up into groups of four students. The groups that are formed are also used in most other classes of the year 1 curriculum and are used to provide a learning support group for each student since it is believed that students are at their most vulnerable during the first year of their university education.

Figure 2 Classroom design to encourage group discussion

A seating arrangement is provided for the students so that they can work together in the class. The allotted tasks can either be given as an individual exercise or as a group exercise.
depending on the purpose of the exercise. However, the main benefit of placing the students in groups is to encourage peer instruction, to enhance discussion and to provide a supportive environment in the pursuit of improved learning. The importance of this to our teaching methodology is reflected in the redesign of our teaching rooms. Figure 2 shows a modified lecture room which has been designed to encourage inter-group discussion by providing curved tables with seats of four. This enhances face-to-face communication within the group, which overcomes the less satisfactory positions for students in the outside seats in a linear table design.

Classroom Communication System. By far the most effective contribution to providing active engagement with the instructor in a large class environment has been the use of a classroom communication system. This allows the polling of the students for their response to a particular task and provides immediate feedback on the students performance. There are a number of commercially available systems. However, the one used here is called a Personal Response System (PRS), and can be obtained from Educue Ltd. (www.educue.com). It is a simple and easy to use system that allows the student to respond with a number from 0-9 and a confidence level. Figure 3 gives an indication of the system in action. The question is presented on the right hand screen in Figure 3. The students respond using the hand held device and the responses are then transmitted automatically. The results are presented as a bar chart if the question is in a multiple choice format.

![Figure 3 PRS System in operation](www.educue.com) (see www.educue.com for more details)

Team Teaching. The development and application of alternative teaching methodologies has been significantly improved by the encouragement of a team teaching approach. Variants of the above methodology have also been implemented in year 1 classes in Engineering Mechanics and Engineering Mathematics and together with the Thermodynamics and Fluid Mechanics class constitute one third of the first year course. Thus, much of the common requirements such as the development and organization of groups, use of technology, teaching experiences and identification of students with difficulties can be shared within the teaching group. This has allowed the increased development time associated with new
teaching methods to be reduced but has also provided a supportive environment to resolve problems and improve teaching. In all, about seven academic staff use the techniques discussed in the year 1 classes.

Staff Development. Prior to introducing the interactive teaching techniques into the course, significant resources involving staff time and financial were devoted to investigating modern teaching methodologies and how they might be implemented. Over a period of about a year, reviews of the literature, attendance at conferences, and information visits to university institutions (mainly in the US), were carried out by various staff interested in applying the techniques. This created a firm basis to implement the techniques and also allowed specific variants to be developed for the course at Strathclyde University.

The teaching methodology discussed above is generic and therefore applicable to a wide range of learning requirements. The specific application to the teaching of Thermodynamics and Fluid Mechanics required the development of new materials appropriate to that subject. Out of class reading was established using a set of class notes and a class text. The class notes described the main material to be taught and established the extent of the course; it also provided homework exercises. The class text is used to provide a greater depth of explanation than the notes can provide. The importance of the notes should not be underestimated. Since the class time is now being devoted primarily to challenging the students knowledge, the acquisition of that knowledge occurs more during home study and differs from a standard lecture delivery. Thus the class notes must also take the form of a study guide and a reading guide, in addition to the presentation of the class material. The basis of this teaching approach is to make sure that the students are actively involved in learning the material by completing a series of tasks which they then obtain almost instant feed back.

**Figure 4 Examples of Task**

The form of the tasks set depends on the complexity of the task. For tasks that can be completed within a short time frame, say 3 or 4 minutes and consist of small elements of knowledge, then the use of the classroom communication system is ideal. For example, testing the use of terminology, physical concepts, fundamental principles and even short numerical calculations can be effectively used here. Multiple-choice questions are

---

**Consider two identical pieces of wood being held under water as shown.**

Is the force acting on A to hold it in place

(1) larger than B  
(2) the same as B  
(3) smaller than B

---

**Heat is transferred to a piston/cylinder arrangement. The gas enclosed within the system expands and the process path is as shown. The atmospheric pressure is 1 bar**

What is the work done by the air to raise the mass and compress the spring?

(1) 1.45 x 10^5 J  
(2) -1.45 x 10^5 J  
(3) -1.2 x 10^5 J  
(4) 1.2 x 10^5 J  
(5) 0.25 x 10^5 J
appropriate and an example of these is shown in Figure 4. However, if the learning requirement is the integration of a number of elements, then a variant of the above technique is used. Most realistic Thermodynamic and Fluid Mechanics based problems are tackled using a procedural approach and require the integration of knowledge obtained from the understanding of the terminology, physical principles mathematical representations, mathematical solution techniques etc. The teaching of these problem solving techniques takes longer and is more complicated. However, the application of the learning cycle whereby the student is actively involved can similarly be applied. Figure 5 shows a typical exercise.

<table>
<thead>
<tr>
<th>Application of Bernoulli Equation (Flow from a Tap)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water flows as a jet from a tap as shown. By applying the Bernoulli Equation and noting that the pressure at the surface of the jet is at atmospheric pressure calculate the velocity of the jet and the jet diameter at 1, 2, 5, and 10 cm below the tap outlet. The velocity of the jet at tap outlet is 0.3 m/s. Density of water is 1000 kg/m$^3$.</td>
</tr>
<tr>
<td>$D_0 = 1$ cm</td>
</tr>
<tr>
<td>$0.3$ m/s</td>
</tr>
</tbody>
</table>

Start by following the procedure below

**Part 1**
(i) Sketch the water jet
(ii) Identify a control volume for each of the conditions to be calculated
(iii) Apply Bernoulli Equation and the continuity equation to each control volume and determine the velocity and diameter.
(iv) Plot the jet diameter (or radius) versus location

**Part 2**
(i) Re-assess each step of the calculation process and identify the importance of that step to achieving the overall objectives.

*Figure 5 Example of Numerical Based Tasks*

### 3 Evaluation

The general teaching methodology described above has undergone significant evaluation, mainly in the US (Mazur, 1997). The implementation at the University of Strathclyde has undergone more limited assessment but generally confirms the main conclusions of the US studies. However, what is also important is to continually assess whether the instructors are implementing the techniques effectively. This has been done in several ways but uses the fact that the year 1 class for Thermodynamics and Fluid mechanics has normally a total roll of approximately 230 students. The class is taught in two streams: Stream A is taught using the methodology described above, Stream B is taught using a traditional 1 hour lecture (no structured interaction) followed by a 1 hour tutorial period. The same class notes and class text were used and the same assessment procedure. Each stream was taught using different lecturing staff. However, all instructors were familiar with the course and have taught the subject for many years. In the following we have given an indication of how the students and staff perceive the techniques qualitatively.
Student understanding
During week 5 and week 10 of a 12-week teaching period students were asked how they rated their understanding of a number of topics which both streams had been taught (0 indicating low confidence and 1 very confident). In week 5 students were asked about topics 1-3 in Table 1, while in week 10 they were asked to comment about topics 1-6. The attempt was to obtain an indication of how the students perceived their own progress. Figure 6 indicates the relative confidence of each stream.

The data in Figure 6 shows that the students in stream A (interactive learning) were generally more confident in their understanding than stream B (lecture approach) and is indicative of an improvement in the learning process. By week 10, both streams show an increased confidence in the subject but Stream A still indicate a greater confidence in their understanding.

Student Comments
In addition to the quantitative assessment described above, the students in stream A were interviewed within their groups and asked to comment on various aspects of their learning experiences during the teaching sessions. In comparison to more common non-interactive lecture process, they were prepared to comment the following:

On group discussion

‘(I like) discussing answers to the PRS questions because it wakes you up and gets you involved with classmates’

‘Hearing different perspectives on topics helps you strengthen your own understanding by making more connections and links’

On learning by questioning

‘You have more time to think in that class because it’s structured, it’s broken up. In a standard lecture it’s difficult to spend time understanding the concepts… you’ve got to keep up with the lecturer… going ten to the dozen.. and take notes. I mean in an ordinary lecture you might get through a lot but you won’t understand what’s going on.’
‘Doing a question right after a presentation by the lecturer helps you to understand and remember the concept’

These comments were obtained from a study to investigate the effectiveness of the approach and were representative of the positive attitude of students to the teaching style used.

Instructors Assessment
The implementation of this teaching methodology has continually been reviewed by the staff associated with the classes. This has allowed a number of general points to be made:

(i) The development of teaching material to support the methodology is more onerous than for a standard lecture approach. Appropriate student based self study aids are required since time allocated to going over the content of the notes is significantly reduced. A data bank of questions and tasks are required. The development of good questions is not a straightforward task and usually requires a number of iterations to determine the correct level of difficulty.

(ii) While the delivery of the class need not be dependent on the technology (PRS system in particular) the teaching staff soon become very reliant on its availability.

(iii) The classes are much more enjoyable to deliver. Staff-student interaction is increased and there is a much greater sense of being involved in the learning process.

(iv) Importantly, the difficulties that students are encountering are now far more apparent and the ability to respond to them quickly can be more effective.

(v) Instructor’s knowledge is challenged much more in this environment and therefore leads to improved understanding.

(vi) In this style of teaching the instructor is more conscious of the progress the students are making on each topic. It is therefore up to the judgement of the instructor at what pace the class content should be taught based on how the majority of the class is responding. It is easy to judge wrongly and find that too slow a pace has led to loss of part of the syllabus. Alternatively, you may easily find that a re-assessment of the syllabus is required for the time available, to ensure effective learning.

(vii) The delivery of the class in an interactive manner takes longer to develop than a standard lecture. However, once developed, the pre-lecture preparation time is shorter unless special action is required to accommodate learning difficulties, which have arisen from previous classes. The response to these difficulties may lead to the overall delivery of the class requiring more effort than a standard lecture delivery.

The evaluation of the teaching methodology has indicated that what we were led to expect of the techniques does actually happen. That is, a general improvement of the learning process during a teaching session.

4 Difficulties with Thermodynamics and Fluid Mechanics

So far the discussion has been mainly devoted to general features of the teaching method and only limited discussion on specifics of Thermodynamics and Fluid Mechanics teaching. The ability to interact with the students provides access to the thinking of the students and the difficulties that they encounter. These tend to be numerous, if not infinite, and are not always related to Thermodynamics or Fluid Mechanics, (for example their previous Physics or Mathematics knowledge may be poor, so might their study habits be, etc). Below is a
summary of the main issues that we have identified and that the students find difficulty with. They require to be addressed in the teaching of the subject. However, it should be noted that the comments pertain primarily to the syllabus discussed in this paper, but should be of sufficient generality to relate to other courses in Thermodynamics.

(i) Terminology that is used is a mixture of familiar terms (eg, heat and work) that require a more rigorous definition and new ones (eg, internal energy, reversible, process path). The large number of terms and their connection to their application require emphasis in a variety of examples for the students to appreciate their importance and usage.

(ii) The calculation of work for a closed system \( W = \int P \, dV \) is particularly troublesome due to the variety of process paths that are possible. Identification and use of process paths requires special attention. Furthermore the use of the same process paths for open and closed systems requires particular attention.

(iii) How to model a real thermodynamic system (refrigeration or gas turbine plant) and reduce it to a simplified thermodynamic representation capable of being modelled is difficult for the student and requires a gradual development as the model equations are developed.

(iv) The development and use of the numerous concepts and equations to solve Thermodynamics based problems require continual overviews and summaries to show the connection between the big picture and the details. The link between the basic physical principles, the mathematical representation and numerous constitutive relationships (ie property relationships, process paths, etc) are particularly troublesome.

(v) In the teaching of Fluid Mechanics problem solving, the general need to consider both the energy equation and the continuity equation together as a simultaneous equation system requires to be presented and emphasised.

In each of these cases, action can be taken to overcome the difficulties by devising specific tasks to allow the student to explore the problems in detail.

5 Conclusions

The introduction of a more interactive approach to teaching large classes is believed to make an improvement to the teaching and learning of Thermodynamics and Fluid Mechanics. The use of student groups and assistance of a classroom communication system together with a team teaching approach makes peer instruction and an interactive approach particularly viable.

6 References

Bligh A.B What’s The Use Of Lectures, Penguin Education, 1971

Boyle J.T., Nicol D.J. The Impact Of Classroom Communication Systems, Peer Discussion and Prompt Feedback on Student Learning in a Large Class Setting, International Conference on Communication, Problem Solving and Learning, Glasgow 2001


Lewins, J.D. Teaching Thermodynamics, Proceedings of a Workshop held at Cambridge University, September, 1984.


W.M DEMPSTER
Dr Bill Dempster is a lecturer in Mechanical Engineering at Strathclyde University, UK. He received his undergraduate degree from Glasgow University (1981) and Masters (1983) and PhD (1995) from Strathclyde University. His main research interests are in the field of industrial Fluid Mechanics and in particular two-phase fluid mechanics. His teaching interests involve curriculum development and the application of active engagement techniques to large class environments.

C.K.LEE
Dr C. K. Lee is a Senior Lecturer in Mechanical Engineering at Strathclyde University. He received his undergraduate degree (1963) and Ph.D (1966) in Mechanical Engineering from Strathclyde University. His main interests are in the field of thermodynamics and heat transfer with specific interests in gas dynamics and automotive engine analysis. His teaching interests include development of techniques in peer assessment and peer instruction.

J.T.BOYLE
Professor Jim Boyle is the Head of the Department of Mechanical Engineering at Strathclyde University. He received his undergraduate Degree in Mathematics (1972) from Strathclyde University and his PhD (1975) and DSc (1988) in Mechanical Engineering from Strathclyde University. His research interests are in the field of structural mechanics with particular emphasis on finite element methods applied to pressure vessel problem. He is particularly interested in developing a conducive environment for student learning through interactive engagement techniques.