Teaching Thermodynamics

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PREFACE

It seemed appropriate to arrange a meeting of teachers of thermodynamics in the United Kingdom, a meeting held in the pleasant surroundings of Emmanuel College, Cambridge, in September, 1984. This volume records the ideas put forward by authors, the discussion generated and an account of the action that discussion has initiated. Emphasis was placed on the Teaching of Thermodynamics to degree-level students in their first and second years.

The meeting, a workshop for practitioners in which all were expected to take part, was remarkably well supported. This was notable in the representation of essentially every UK university and polytechnic engaged in teaching engineering thermodynamics and has led to a stimulating spread of ideas. By intention, the emphasis for attendance was put on teachers of engineering concerned with thermodynamics, both mechanical and chemical engineering disciplines. Attendance from others was encouraged but limited as follows: non-engineering academics, 10%, industrialists, 10%. The record of attendance, which will also provide addresses for direct correspondence, will show the broad cover achieved.

I am indeed grateful for the attendance of those outside the engineering departments who in many cases brought a refreshing approach to discussions of the 'how' and 'why' of teaching thermodynamics. It was also notable that many of those speaking from the polytechnics had a more original approach to the *teaching* of thermodynamics than those from conventional universities. The Open University however brought their own special experience to bear.

The record of the Workshop given here is organized in accordance with the six working sessions. Theme and contents of each session are shown in the Table of Contents. The sessions are given in the sequence of the full papers presented to the Workshop, followed by the summaries of short papers discussed in the same session and closed with the record of

discussion. I am most grateful to the Session Secretaries who, together with the Session, Chairman, recorded, edited and transcribed the fast moving discussion.

Session One is notable for the theme paper prepared by Professor Bill Woods. In 1980, five years earlier, the Institution of Mechanical Engineers organised a not dissimilar conference in respect of the teaching of Fluid Mechanics and Thermodynamics. That meeting was therefore directed principally to mechanical engineers; the present Workshop sought to integrate views on chemical engineering and engineering science more widely and to omit aspects of fluid mechanics and heat transfer. Nevertheless, it was important to comprehend what the views of teachers were five years earlier and to see what progress has been made. The opening paper served this purpose admirably.

Session Three, held in two parallel sessions, was different from the rest in being devoted to demonstrations of laboratory teaching aids and the usage of microcomputers. Micro- or personal computers were used in two senses: to manipulate data arising from laboratory work and as teaching aids. Several useful programs of the latter sort were made available at the Workshop and can be ordered by the reader direct from the authors reported in Session Three.

The remaining sessions were of the more conventional type and are recorded here in their working order. In one sense the Workshop achieved for its delegates something that at best will only rub off second hand in this more formal record, a sense of *cameraderie* between those who had spent the previous years teaching 'first pass' thermodynamics. Titles in the workshop reflect some of the attitudes of teachers, on the lines 'Why has Thermodynamics become a Difficult Subject?' The act of coming together to evaluate the difficulties had a cathartic effect, removing some of the loneliness that can be felt. It was the evening address by Sir Brian Pippard, FRS, that perhaps brought most relief and solace to the weary; we were comforted to learn that other topics too were difficult to teach; that to the broader view of a physicist, equilibrium systems meant universal helium and our own concerns were somewhat petty metastable and transient considerations!

Why should thermodynamics be difficult to teach? If we compare the concepts involved to those forming the basis of Newtonian mechanics, there are some useful comparisons. The

laws of motion have imbued themselves in our civilization for some three hundred years; the laws of thermodynamics for little over one hundred. The difficulties that originally faced the acceptance of Newtonian mechanics are to a large extent those that lie at the heart of thermodynamics. How absurd to say that matter would continue in motion in a straight line when common observation shows mechanisms to run down. Now that our civilization is conditioned to accept Newton, how are we to readapt to Kelvin and Clausius?

The confused history of thermodynamics in the eighteenth and nineteenth centuries has left an immediate legacy of terminology that does not help the student. The teacher, who has studied thermodynamics on at least three levels, has his own difficulties in understanding what the student's difficulties are. The nineteenth century approach to thermodynamics via the process occurring between systems, especially the cyclic process, has left a confusing terminology. If heat is energy in transfer, what is the subject of 'heat transfer'; if heat is that transfer of energy that is not work, have we not *defined* the Second Law that forbids the complete transformation of heat to work; if heat is to do with interactions between systems, why is 'heat capacity' a property and not a process. Terms such as adiabatic (no through path) lack precision; if isothermal means constant *temperature*, why diathermal for *heat*?

An approach favoured by some teachers is to seek rigour. Pippard, in a characteristic remark, warned us that rigour was for mathematicians, not for physicists and certainly not for engineers. Our attempts at rigorous thermodynamics were illusory. What seemed more sensible was to develop the language and laws of thermodynamics in a suitable context. In this regard the work of Haywood and Brazier in developing the 'Law of Stable Equilibrium' as a teaching mechanism seems to me to be of significance. The importance is that one can discuss the nature of systems to include their 'running down' in terms of their properties rather than interactive processes between systems. The material given in Session Four should enable all teachers of thermodynamics to follow up the original Hatsopoulos development in a practical way.

The alternative method of development that was given preference by contributors is perhaps most pungently given by MagLashen to chemical engineers (see bibliography), as an axiomatic development which states the nature of entropy and allows rapid derivation of conventional laws from so succinct

a base. There is I think some unease amongst mechanical engineers that the traditional cyclic process route should be a result and not a forerunner of this approach.

In respect of the teaching of foundations, two other areas were explored. Many are concerned with the limitations of conventional thermodynamics to bounds on processes achieved under ideal and vanishingly slow conditions. It must be undesirable to present an optimisation in such impractical terms as the infinitely slow reversible process when real engineering is to do with reconciling capital and running costs. Silver's presentation of irreversible thermodynamics in Session Six then was a welcome attempt to meet this challenge for thermodynamic realism.

The second area concerning foundations would be the place of statistical thermodynamics in an initial course. Our physicist colleagues in many cases have come to grips with the problem, recognising that modern physics is nothing without quantum theory. If indeed quantum theory is accepted, the distinction between heat and work is perhaps made plainer, and more rigorous, than macroscopic processes can ever achieve. Those at the Workshop, with their experience of engineering students were, shall we say, lukewarm to the plea for a statistical starting point. It is puzzling, however, to account for the different capabilities of students of modern physics and modern engineering; one must allow the alternative hypothesis, that the distinction is in the teachers not the taught.

Session Five explored the developing discipline of exergy studies at what would probably be called a 'second pass' level rather than a first teaching level. The terminology 'exergy' is beginning to be accepted in UK after its development on the Continent. Several authors at the workshop attempted an exposition to show how exergy might provide the framework of a practical and useful 'Second Law' analysis, useful in that it would lead to design and synthesis and hence a more valuable role for thermodynamics. We are grateful indeed that the Royal Society should allow us to include Professor Linnhoff's Esso Award Lecture in these proceedings. Perhaps what is needed is a development of nomenclature to distinguish *available* power from power in the same way as exergy distinguishes available energy from energy.

FUTURE WORKING GROUPS

This brings me to discuss the three areas in which The Workshop identified a need for continued study. These three areas were:

- (i) The rationalization of nomenclature,
- (ii) The evaluation of teaching objectives and methods,
- (iii) The development of exergy studies, analysis and synthesis.

Nomenclature

The peculiar terms of our discipline must be seen as one of the difficulties of the subject. Let me put this in the context of the prospect of intelligent or expert systems, computer programs provided with enough information and a set of algorithms that they will guide us through a thermodynamic analysis. What would such a machine make of 'heat', isothermal versus diathermal, or heat capacity? Indeed what do our *teachers* make of heat capacity? One of the most vivid recollections I have of the Workshop is the *identical* arguments put forward by two strong minded teachers, arguments that paralleled each other exactly except that one used the set to promote the term including 'capacity' and the other used identical arguments to exclude 'capacity' from the terminology. (And this twenty years after apparent international agreement on terminology.)

There is a major need to rationalise our terminology. It will be painful for teachers but not I suspect for students. Chemists faced similar problems but have successfully overcome them.

I am glad that one of the initiatives arising from the Workshop is the establishment of Working Group No. 1 on nomenclature and units under the chairmanship of Dr. Y. Mayhew (University of Bristol). In this field, as in the topics of the next two Working Groups, readers are invited to get into contact with the Chairman to contribute to the topic.

Teaching Methods

The second Working Group, under the chairmanship of Dr. W. Kennedy of the Faculty of Technology in the Open

University, has undertaken to review and promote questions of teaching objectives and methods in thermodynamics. Here the new technology associated with computers has importance at many levels. One level might be the availability of computer programs to generate data; another will be the use of computers in a teaching mode if not as an expert system. It was notable that polytechnic teachers had seriously questioned methods of teaching. Proposals for resource-based teaching, relying less on the explicit didactics of the teacher, might indeed have a fundamental role to play.

Exergy Analysis

Finally Dr. T. J. Kotas has undertaken to chair Working Group No. 3 in the prosecution of exergy studies.

Outside the record of the six working sessions, this volume carries the list of those attending with their institutions and a closing bibliography prepared by Professor Button and his colleagues for mechanical engineers with a supplement by Professor Turner for chemical engineers. Quite apart from its value as a record of texts in print, notice might be taken of the suggestion that the act of studying such a bibliography is a learning process, a development in resource based learning.

Copyright difficulties have made it impossible to reproduce the edited text of a reading from the work of Samuel Beckett given after the Workshop dinner by Dr. Nessim Hay and his colleagues. The piece was taken from Lessness and evokes the dead state or the 'entropy death'. Readers who would like to see the original text are referred to the original publication in French as SANS, Les Editions Minuit, Paris, 1969 and the author's translation as LESSNESS, published by Calder and Boyer, London, 1970. A full reading was performed by the BBC in 1971 and a private recording of the presentation to the Workshop was made by Dr. Hay in 1984.

CONCLUSION

I think we may regard the present volume as a valuable source of material relevant to teaching thermodynamics. Many different ideas and some prejudices were ventilated at the

meeting; a good teacher should surely be aware of the issues and possibilities open to him. That thermodynamics is an intellectually stimulating discipline is self-evident to those who took part in our discussions. I think we have some hesitation in claiming too important a role for classical thermodynamics in application when the competing claims of rate processes (kinetics) and their connection with capital costs are contrasted with thermodynamics and running costs. Surely the approach should be to take the best of both and to blend them together?

It is intended to review the findings of the Working Groups with expectation of follow-up action that can be reported perhaps to a successor workshop towards the end of this decade. Thermodynamics has its problems and its challenges but it has by no means reached its 'dead state'.

The sentiment for the future of thermodynamics was put superbly by Sir Alan Cottrell in Session Four. Any teacher of our discipline who wants refreshment at the springs of learning would do no better than to taste Sir Alan's refreshing draft.

Teachers of thermodynamics may also want a longer draft from the new philosophical account of non-equilibrium thermodynamics now available in English:

Prigogine, I. and Stengers, I., "Order Out of Chaos: Man's Dialogue with Nature", Heinemann, London, 1984.

Jeffery D. Lewins

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We are grateful to the Royal Society for permission to bring the Esso Award lecture, John Wiley for a figure in Session Five and To Ellis Horwood in respect of two papers in Session Five. I have acknowledged the labours of Session Chairman and Secretaries and I would couple with this my thanks to the Steering Committee who guided the Workshop.

Several secretaries assisted me during the preparations for the Workshop but I would particularly thank Mrs. Janis Eagle who typed these proceedings from the submitted papers and draft record of discussion.

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