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Aspects of Teaching and Learning with Particular Reference to Internal Combustion Engines and Heat Engines*

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The objects of the paper are to highlight some problems in teaching and to suggest possible remedies, based upon recent knowledge about educational processes. It mentions the educational aspects of (i) different types of learning and (ii) the dimensions of learning and teaching styles. Confusion between thermodynamic heat engines and internal combustion engines is discussed and the relevance of air standard cycles is mentioned. One main conclusion is that the courses should be presented in a variety of styles so there is 'something for everyone'.

NOTATION

Capital and lower case letters

BDC	Bottom dead centre
C_p	Specific heat capacity at constant pressure
C_v	Specific heat capacity at constant volume
P	Pressure in engine cylinder
P_r	Power for retarded ignition timing
P_a	Power for advanced ignition timing
P_{op}	Power for optimum ignition timing case; this is TDC for the air standard cycle case
$R=\frac{V_1}{V_2}$	Normal compression ratio
$R_e=\frac{V_1}{V_2'}$	Equivalent compression ratio for advanced or retarded ignition timing
TDC	Top dead centre
V	Engine cylinder volume
V_1	Engine cylinder volume at BDC
V_2	Engine cylinder volume at TDC

Greek letters

θ	Engine crank angle
$\gamma=\frac{C_p}{C_v}$	Ratio of principal specific heat capacities

Subscripts

a	Advanced timing case
op	Optimum timing case
r	Retarded timing case

INTRODUCTION

ENGINEERING education is facing two particular problems.

1. Many students entering university are generally less well prepared for a course in engineering than they were in the past. Broadening of school curricula and the shortage of specialist teachers in physics and mathematics are probably two of the reasons for this. Therefore, it is now necessary to bring into the first year undergraduate syllabus much material which was once covered at school.
2. Educators are under pressure to reduce the time spent on traditional subjects, such as thermodynamics, but to update syllabuses and to expand the time devoted to some rapidly developing subjects such as manufacturing technology.

There is a general feeling that we are overloading our students and that there is an urgent need both to reduce the material in our courses and to modify the way in which we communicate it.

The paper begins with a mention of recent research into ways of teaching and learning with particular reference to thermofluids. It goes on to consider in detail the differences between internal combustion engines and heat engines and the use of a simple analytical model for estimating the effect of compression ratio and spark ignition timing.

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REVIEW OF RECENT EDUCATIONAL IDEAS

Before proceeding, it is appropriate to consider some of the results of recent research into teaching methods. Sparkes [1] emphasizes the importance of distinguishing between the concepts of skill, knowledge and understanding. A skill denotes the ability to perform a certain task without necessarily having complete understanding of the principles involved; obvious examples are talking and writing. We can test a person's grasp of a particular skill by setting them a task which requires that skill. Knowledge represents information which is committed to memory and can be tested by asking questions which require the reproduction of this information. Understanding demands much more from the student as a firm comprehension of fundamental concepts together with the ability to apply them to the solution of unfamiliar problems is needed. There is no doubt that the main aim of a university course should be to convey understanding. With traditional methods of assessment, the students frequently find that they can do reasonably well in examinations simply by memorizing material and working through past papers, without acquiring a proper understanding of the fundamentals.

Much research has been carried out on the various ways in which students prefer to learn and the ways in which lecturers prefer to teach. Felder and Silverman [2] have identified certain 'dimensions' of learning and teaching styles. They list five aspects of learning, each of which could be handled in alternative ways. Corresponding to these are five aspects of teaching, also capable of being tackled in alternative ways. These are described in the following subsections.

Perception

Most students handle information either by sensory means, observation and experimentation, or by intuitive means, insights and perhaps hunches. In general, according to Felder and Silverman [2] sensors prefer to work with facts and experimental data whereas intuitors prefer theories and principles. Sensors are more comfortable with standard problems and techniques; intuitors welcome unusual problems and are good at innovating. Sensors tend to be slow and careful; intuitors work more quickly but may make more mistakes. The two types of perception correspond to two different teaching approaches, one where the content is essentially factual and the other where the lecturer concentrates particularly on concepts and theories.

Input

The preferred way of receiving information is either visually, through diagrams, graphs, films, and demonstrations or verbally, through written prose and oral lectures and explanations.

Organization

Here there is a choice between inductive organization, which starts with the presentation of facts and continues by inferring the underlying principles, and deductive organization where the principles are adduced first and the applications brought in later. In the first case, the particular leads to the general. In the second, the general, in the form of laws and theories, leads to the particular.

Processing

The student can use the information he or she receives either by active means which involve experimentation, discussing it or testing it in some way, or by reflective means, observation and thinking about it in a more introspective manner. It has been suggested that engineers are usually predisposed towards active learning.

Perspective

The usual teaching process is to cover the material in a logical sequence, pausing from time to time in order to check whether or not the students have an adequate understanding before proceeding to the next stage. This process has been termed sequential learning and it seems to be successful with most students. However, some people learn in a much more spasmodic way. They tend to follow a course over an extended period with only a partial understanding until, suddenly, a point is reached where everything fits into place. These people have been called global learners; their pattern of learning does not fit in very well with conventional methods of teaching and examining but, as Felder and Silverman [2] point out, they often perceive links and connections which are not obvious to others and they may be particularly successful on, for example, a multidisciplinary course.

The foregoing remarks provide only a brief mention of the ideas contained in the paper by Felder and Silverman [2]. Two of the points they make are particularly pertinent. The first is that the method or 'dimension' of teaching that is preferred by most lecturers frequently fails to correspond to the method of learning which is favoured by most students. Research suggests that students tend to prefer visual inputs whereas most teachers rely mainly on verbal presentation. Thus, there is a potential incompatibility which can be partly resolved by the lecturer if he makes appropriate use of graphs, diagrams, films and similar aids. In regard to the organization of the teaching, research has shown that students tend to learn better from the inductive approach whilst teachers tend to favour the deductive. Engineering courses normally start by presenting the fundamentals and then go on to cover applications. The logic of this procedure appeals to the lecturer, who may, however, be in danger of forgetting that an approach which is attractive to him as a person already familiar with the subject, may not appeal to those being taught, who are starting from the beginning. Often there is a need to compromise the aim to preserve rigour in the treatment of the material, while at the same time retaining the interest of the students. First year students are liable to experience some disillusionment if they are bombarded with an unrelieved diet of theoretical principles when the motive behind their choice of an engineering course was, perhaps, a desire to find out more about the workings of engines and refrigerators.

The other point to be borne in mind is that whereas the majority of students may prefer one teaching method, there is no universal agreement. Consequently, the lecturers need to adapt their style to accommodate, as far as possible, the needs of everybody in their class. This may mean making greater use of diagrams, graphs and demonstrations to assist visualization. Setting a number of problems which describe particular processes and asking for an explanation of the fundamental principles involved may encourage inductive learners. It is essential to introduce an adequate number of practical examples and applications in the early stages of the course so that the students can relate them to their own practical knowledge and experience. Doing so benefits sensing learners, inductive learners and global learners.

In relation to what has been said, a number of questions arise. To what extent is it desirable to proceed from the general to the particular and when should the reverse be adopted? In dealing with the relations between the properties of substances, for instance, should we consider the general case of the pure substance first and then proceed to the perfect gas or should we reverse the order?

In other instances, it may be desirable to go from the particular to the general in order to gain the interest of the student and at the same time provide them with a deeper understanding. An example of this is given in the next section.

INTERNAL COMBUSTION ENGINES AND HEAT ENGINES

Consider two spark ignition engines which are nominally identical and suppose that performance tests indicate that their output powers are not the same. Investigation might show a difference in ignition timing and further experiments could provide data to show how variation of ignition timing affects the power output. A similar study could demonstrate the influence of the compression ratio on power. Experiments of this type certainly increase the students' store of knowledge but they do not necessarily contribute towards the students' understanding. By themselves, they tend to lead to what may be termed shallow rather than deep learning.

Now consider the indicator diagram for a gasoline engine and that corresponding to a constant volume air standard cycle shown in Fig. 1 which are based upon a figure given by Rogowski

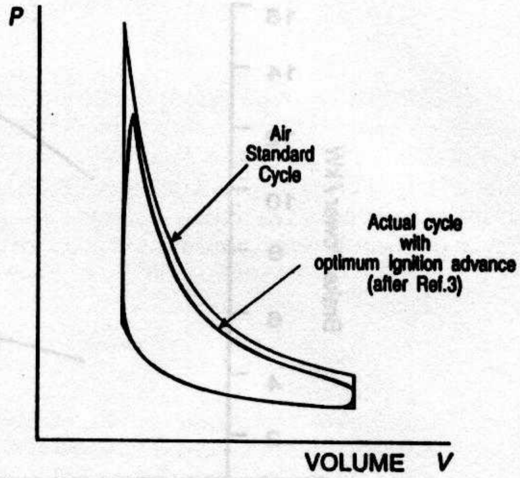

Fig. 1. Indicator diagrams for air standard cycle and actual engine after Rogowski [3].

[3]. The student may have a knowledge of both these diagrams, without necessarily having any proper understanding of the relationships and the differences between them. There is often confusion between internal combustion engines and true heat engines. The differences may be clarified by Table 1.

Students' misconceptions might be said to range between two extremes. On the one hand, the student may believe that the internal combustion engine operates on an air standard cycle and be unaware of the difference between heat engines and internal combustion engines. On the other hand, the student may regard the internal combustion engine as a practical device, completely unrelated to air standard cycles.

In order to make clear the usefulness of ideal cycles and at the same time gain the students' interest in a thermodynamics course, relatively simple exercises involving these cycles can be set. The student can predict the influence of the compression ratio on power output, using the expression for the air standard efficiency of the Otto cycle and compare the values with the experimental data obtained from a spark ignition engine on which the compression ratio can be varied. Figure 2 shows a specimen set of results based on those given by Woods [4]. Other comparisons reported by Taylor and Taylor [5] which use indicated powers are also relevant. It becomes clear to the student that very simple calculations may provide a fairly accurate prediction of trends, even though the absolute values differ markedly. The students will know some of the reasons for this, while others will become clear later in the course.

The air standard cycle can also be used to obtain an approximate prediction of the effect of ignition timing on power output. In the air standard cycle, combustion is simulated by instantaneous heat transfer and the case of optimum ignition timing corresponds to heat transfer at TDC. Ignition timing, advanced by θ crank angle relative to the

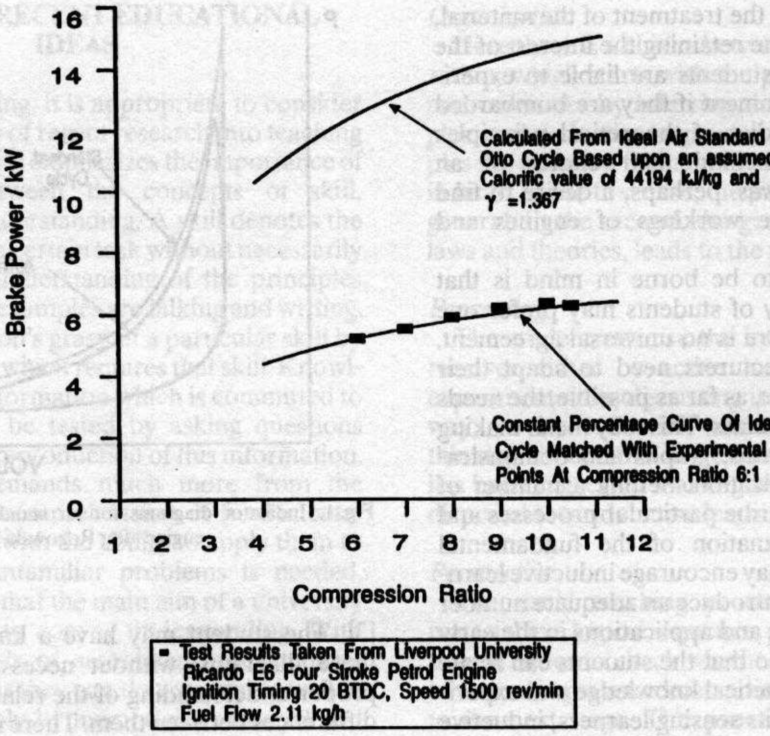

Fig. 2. Power—compression ratios for air standard cycle and Ricardo test engine.

optimum may be represented by modifying the air standard cycle, as shown in Fig. 3. It may be shown that the ratio of the power for the advanced or retarded timing case to that with timing at TDC is given by the expression shown below. This expression is applicable when the ratio of the connecting rod length to the crank radius is large and the angle θ, expressed in radians is small.

$$\frac{P_r}{P_{op}} = \left\{ \frac{1 - \dfrac{1}{R^{\gamma-1}}\left[1 + \dfrac{\theta^2}{4}(R-1)\right]^{\gamma-1}}{1 - \dfrac{1}{R^{\gamma-1}}} \right\}$$

The normal compression ratio is $R = V_1/V_2$ and the ratio $R_e = V_1/V_{2'}$ may be regarded as an

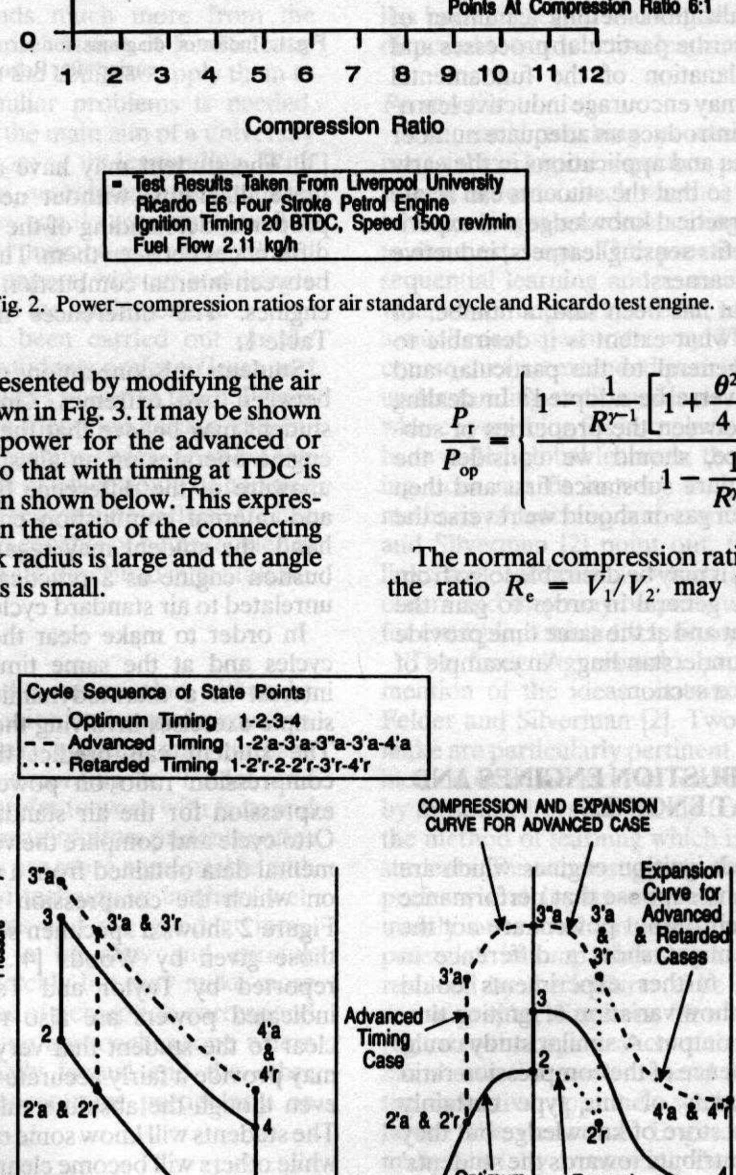

Fig. 3. Indicator and pressure—crank angle diagrams for air standard cycle with optimum, advanced and retarded timing.

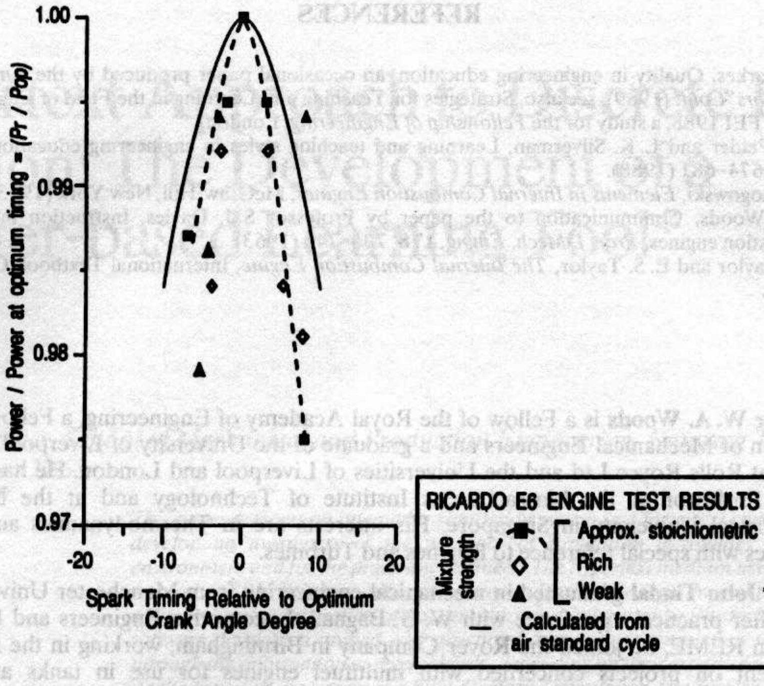

Fig. 4. Power ratio—spark timing results for air standard cycle and Ricardo test engine.

Table 1. Comparison between heat engines and internal combustion engines

Heat engines	Internal combustion engines
A system	A control volume
Thermodynamic cycle	Thermodynamic processes with combustion from reactants to products, not a thermodynamic cycle
Heat and work	Heat and work
Interactions with surroundings	Interactions with surroundings
Surroundings include, high- and low-temperature reservoirs	Surroundings include, , a low- but not a high-temperature reservoir.
A true thermodynamic heat engine	Not a true thermodynamic heat engine
Example: steam power plant	Example: spark ignition engine

equivalent compression ratio for the advanced or the retarded timing cases.

Figure 4 shows a comparison between relative power outputs at different ignition timings, as predicted from this simple model and actual power outputs from an engine, measured on the test bed. Once again, the simple model predicts the trends quite well. These calculations can usefully lead to a discussion of the way in which the power of computers has led to the development of more complex models, producing more accurate predictions and allowing simulation of almost all the processes taking place in the engine cylinder. This, in turn, produces a much improved understanding of events and allows a significant reduction in development testing.

CONCLUSIONS AND RECOMMENDATIONS

1. The lecturer should be aware of the different 'dimensions' of teaching and learning and should recognize that an approach which appeals to the educator may not be the most suitable for the student. It is desirable to employ a mixture of styles in order to accommodate, as far as possible, all types of student. It is essential to teach the fundamentals with an adequate treatment of applications, partly in order to prepare graduates for their entry into industry and also to retain their interest. It is important to instil into the students sufficient confidence in their own ability to apply their comprehension of fundamentals to the solution of practical problems.
2. The simple exercises concerning the influence of compression ratio and ignition timing on power output are examples of methods which may be used quite early in the course to emphasize the significance of fundamental principles.

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