The planning and developing of an instructional system based on the classroom use of textbooks, with reference to energy, entropy and irreversibility

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The objective of this project was the planning and development of a physics learning system using the principles of educational technology. Its starting point was the classroom use of a textbook.

The research team decided to base the system on the classroom situation as it exists, taking due note of (a) the 'motivation and the degree of proficiency of the teachers, (b) the books, experimental equipment and audio-visual resources available and (c) the social, economic and cultural levels of the students.

This realistic approach led the team to start with an existing textbook and then to strive for the optimisation of its use in the classroom. At the core of this process, they placed reading and discussion, supplemented by group work, practical work, etc.

It was appreciated that the textbook's qualities of clarity, intelligibility, precision, etc. would play a fundamental role in the whole process - even to the extent of determining the success or failure of its application. It follows that the approach adopted may also serve to diagnose the didactic quality of textbooks.

AN EDUCATIONAL TECHNOLOGY MODEL FOR THE CLASSROOM USE OF TEXTBOOKS

Planning the activities

Before using the proposed technique, the teacher must himself read the textbook in order to acquaint himself with it, to analyze the content and the presentation, to gauge the intelligibility of both text and the illustrations and to check the suitability of the exercises proposed. A full diagnosis and analysis might take two or more readings.

During this diagnostic period, the teacher will try to specify his objectives and to match these to possible student activities which will include (a) reading the text, (b) discussion, (c) clarification and/or explanation by the teacher as points arise during the discussion and (d) doing exercises (whether individually or in groups).

Specifying the objectives themselves will depend on the teacher's approach to the subject matter, on his professional experience and on his proficiency in the subject. In the first instance, this is best done in terms of task specification; the operational statement (i.e. the questions and answers which can be accepted as evidence that the proposed objectives have been achieved) follows later. This specification of basic objectives is essential since it is these objectives which serve as guides to all the activities undertaken in the classroom.

The ease with which teachers describe these basic objectives is a function of the quality and clarity of the text itself. Difficulties may arise if the text is incomplete, ambiguous and therefore confusing, or illogically' sequenced. This provides a very good test of the quality of the text. One of inferior quality will give rise to unsatisfactory learning and will demand extra effort from the teachers to explain the difficulties it creates.

It will be necessary, whilst reading the text, for the teacher to assess the likely familiarity of any prerequisites (in physics or mathematics) to the students. Once this has been done, the teacher will be able to plan the necessary revision, either by direct teaching and discussion, or by the use of printed materials for reading and debate. He must make such revision dynamic and interesting since its success is essential.

Since the objectives are to be attained by reading and group discussion as well as by the solution of problems (or exercises), the teacher must facilitate the process by determining precisely what is to be read, estimating the time required, specifying the problems to be solved (either individually or in groups) and preparing himself to explain whatever may be necessary when those problems are attempted.

Immediately after the reading by the students, the teacher should initiate a discussion on the main topics covered. His own contribution to this must be carefully planned and he must be prepared to clear any doubts and to answer any questions which may arise. Ideally, he should guide the discussion so that the group can itself answer its own queries and resolve its members' difficulties.

The teacher's plan will include a list of the items to be reviewed (succinctly), of questions to be asked and such other matters as may be of interest.

Difficulties experienced by the students during their reading have to be diagnosed so that they may be dealt with during the discussion. If necessary, the teacher may need to explain some points of obscurity in greater detail than the text provides.

It may be necessary to establish some supplementary objectives which have particular reference to the theme in question. These might allow the teacher to elaborate on the subject matter of the reading and to analyze, in depth, other aspects of the theme. In doing this, the teacher brings his own personal touch to the material of the text.

The teacher must steer a path between, on the one hand, establishing too many supplementary objectives (which would imply that the text was inadequate for his purposes) and, on the other hand, accepting that the established basic objectives are entirely sufficient.

Establishing such supplementary objectives makes it necessary to determine the activities proposed -explanation, readings of other texts, performing experiments, viewing films etc. and the discussion which will follow.

It is vital to maintain the students' motivation at a high level both before and throughout their reading. Teachers need to provide for this by, for instance, reporting historical events relating to the subject matter or to the lives of the scientists involved, offering relevant anecdotes, proposing problems for solution, demonstrating suitable experiments, presenting films, slides and other audio-visual material.

Criteria for the assessment of the students' learning depend on the specification, in operational terms, of the basic and the supplementary objectives. This process, too, requires careful planning, and the teacher must ascertain whether, on average, the students have attained the objectives proposed.

Should the assessment be based on written tests, individual corrections must be made as soon as the students hand in their papers. Doubtful points may be explained after this has been done.

Should the assessment be oral, the teacher must attempt to include all the students. This is a simple way to assess achievement of objectives lesson by lesson and assessment can take place simultaneously with the discussion.

Once the planning is complete, the teacher will have available: (a) a list of basic and supplementary objectives, (b) a list of pre-requisites with plans for their treatment, (c) plans for discussions on the reading which has been done, (d) plans for relevant activities, (e) plans for ensuring motivation and (f) plans for assessment. Item (a) apart, these do not require too much effort from the teacher. But they will enable teachers to conduct their classes in an organized and controlled manner.

Carrying out the activities

Once the planning stage has been completed, the classroom activities follow in sequence. The order may be adjusted to suit the subject matter, Or the needs of the students, or the availability of time, but it may be summarized thus: (1) revision of the pre-requisite material, (2) motivational activities, (3) reading the text, (4) discussion, (5) activities related to the objectives (both basic and supplementary), (6) assessment, correction and discussion, and (7) final assessment.

Revision. Revision of the pre-requisites by the teacher can be offered as a lecture (in which the teacher must ensure the participation of all the students by his use of such questions as 'What is the first law of thermodynamics or 'Which process is used to solve this equation?') or as the reading of a text followed by a teacher-led discussion.

Motivation. Whatever the method used to provide motivation (lecture, anecdote, practical work, demonstration, etc.), it is essential that all should be fully involved. If convenient, the scheme for motivation may precede that for revision.

Text reading. Once sure of the motivation of the students, the teacher should encourage the group to proceed with the reading activities he has planned. He should write the appropriate page numbers, the time available and the list of the basic objectives on the blackboard so that everyone knows precisely what is required. When such work is undertaken for the first time, a group will require guidance. They should be told that although the reading has to be done individually interaction among the participants (covering explanations, the exchange of opinions, etc.) is allowed, that they should make notes of any doubts they may have so that these may be considered in subsequent discussion and that they may consult the teacher.

Discussion of the reading. Using the plan he has prepared, the teacher will lead a discussion on the material read; such a discussion should relate to all the material covered and should include questions addressed to individual students. The teacher may find it necessary to stimulate discussion, to ask questions and to raise difficulties himself. This will be especially true in the early stages for then students are unwilling to participate fully. But, as they recognize the essential part played by discussion in the learning process, this will change.

Activities related to the basic and supplementary objectives. These include the reading itself, the discussions and explanations as well as the problem-solving exercises. The teacher, having ensured that the reading and the discussions are complete, has next to coordinate the doing of the exercises and to provide the other activities he has planned. And, in the final minutes of a lesson, he may wish to return to the motivation theme.

Assessment, correction and discussion. Once the planned programme is complete, the teacher must assess whether or not his objectives have been achieved. This requires the students to perform the assessment tasks, the correction of any papers submitted and the clarification of any remaining difficulties.

Final overall assessment. The teacher may wish to effect a final assessment when his class has completed a theme or a chapter. This might give opportunity for further discussion.

The entire scheme outlined above is not intended to be rigid. It will require reformulation to adapt to the learning conditions which obtain. But the central part played by the reading must remain since all the other activities have been developed around it.

A SAMPLE SECTION FROM THE TEXT

To illustrate how the model operates, a text was written at a level suitable for secondary schools on the topic of 'Energy, Entropy and Irreversibility. It was the intention to offer, in form and content, a traditional text, rather than to prepare a didactically sound one, for a basic objective of the project was to present a model applicable to any existing textbook, independent of its didactic quality. The contents are listed in Table 1.

The sample will be restricted to items 1, 2 and 3.

TABLE 1. Contents of the whole text.

I . Physical systems; the boundaries and the surroundings of a system; open and isolated systems.

2. Natural processes and the orientation of spontaneous physical processes.

3. Reversible and irreversible processes.

4. Heat engines; Carnot's cycle.

5. Entropy: the second law of thermodynamics.

6. Conclusions.

7. Exercises.

1. Physical systems; the boundaries and the surroundings of a system; open and isolated systems.

(a) *Physical systems.* In studying any natural phenomenon we concentrate on a restricted area within the universe. Consider the following instances: (i) the detonation of an explosive somewhere on Earth; (ii) the melting of an ice cube in a container of warm water; (iii) the path of a charged particle in the electric field between two parallel plates; (iv) the behaviour of a gas contained in a cylinder fitted with a moving piston.

Each of these examples restricts our attention to a limited part of the universe. Any part of the universe isolated for such study may be called a *system. A system is any part* of *the universe which is isolated either physically or mentally for the study of its properties.*

Thus a chemical or a nuclear explosive can be considered as a system. A container filled with water and ice is a system which may be studied for its thermal properties. The parallel plate capacitor and the charged particle form an adequate system for the study of the behaviour of charges in nearly uniform electric fields.

(b) *System boundaries.* Let us consider a system comprising a gas contained in a cylinder which is fitted with a moving piston (figure 1). The surface that circumscribes the system is named the *boundary of the system.*

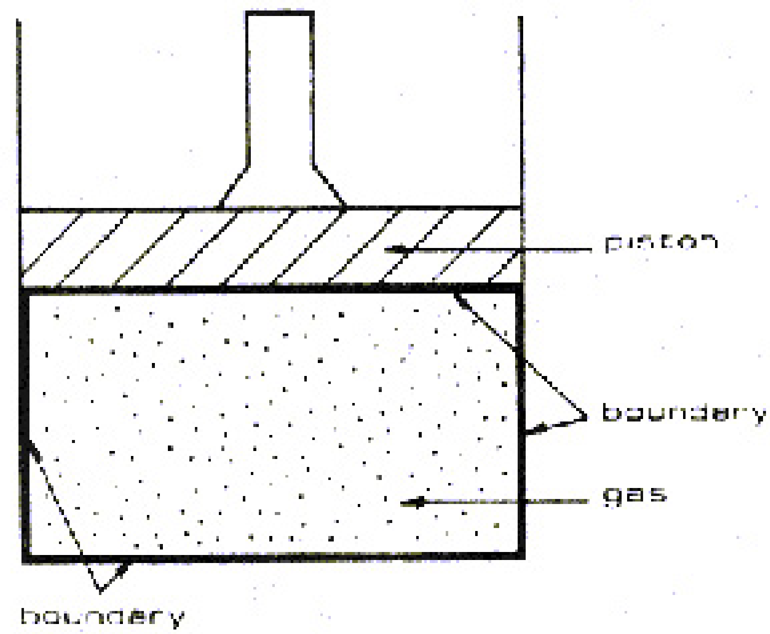

Figure 1. The boundary of a system is determined by the surface that circumscribes it.

Boundaries may or may not be fixed. When the gas within the cylinder acts on the piston and moves it, we have a *moving boundary.* On the other hand, a thermos bottle is a system with a *fixed boundary.*

(c) The surroundings of a system. In the example of figure 1, the gas, the cylinder and the piston constitute a system with boundaries as shown. The remainder of the universe constitutes the system's surroundings (figure 2).

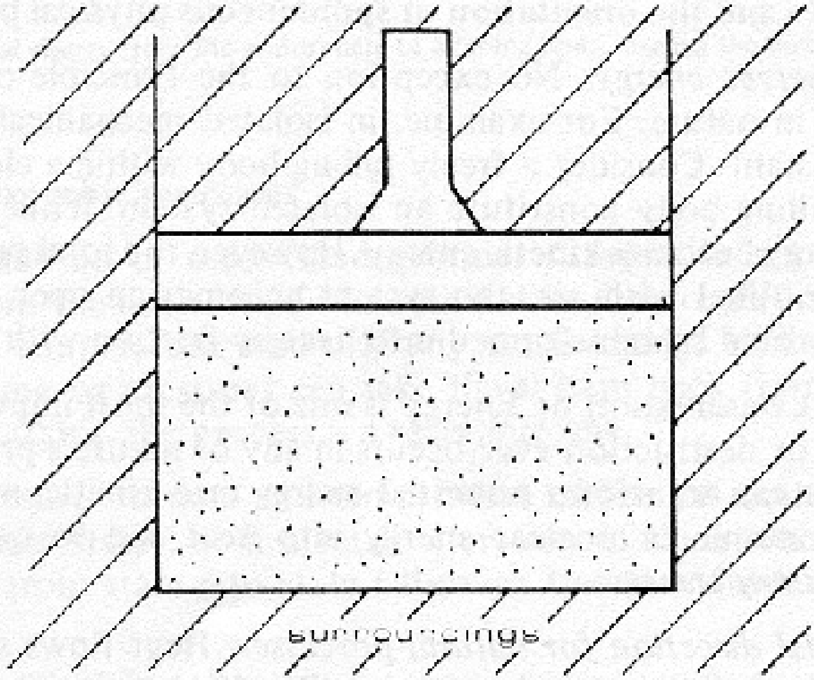

Figure 2. The surroundings of a system make up the environment in which it is located.

A system's surroundings may also be called the *environment* in which it is located. A system's environment exerts direct or indirect influence over the system. In this case, the atmosphere that is part of the system's environment exerts pressure on the piston.

(d) *Open and isolated systems.* Systems may be either *open* or *isolated.* For example, man is an open system since he interacts with his surroundings. He inhales, exhales, eats and so on. A truck loaded with sand that is shedding part of its load is an open system, since it transfers matter - mass - to its surroundings. A good, firmly closed thermos bottle can be considered as an isolated system for a certain, short interval of time since, during that interval, it exchanges almost no energy (heat) or matter with its surrounding environment.

An *open system is* any system that interacts with its surroundings, exchanging matter and/or energy with its environment (figure 3). An *isolated system is* any system that does not interact with its surroundings; no energy and/or matter interchange with the environment occurs.

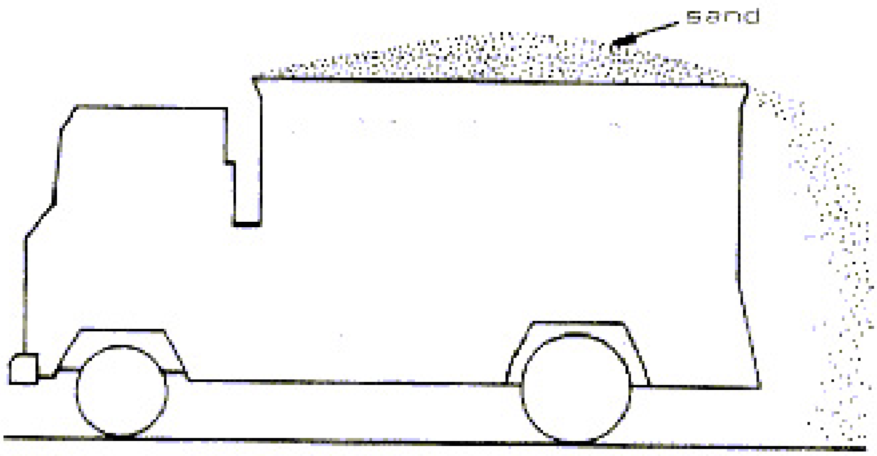

Figure 3. A truck loaded with sand that sheds part of its load is an open system.

2. Natural processes and the orientation of spontaneous physical processes.

(a) *Nature conserves energy. No* exception to the Principle of Conservation of Energy has ever been observed in nature. For example, in isolated mechanical systems, the total mechanical energy remains constant. Consider a freely failing body within a closed vacuum tube. In this case the tube and tile falling body constitute an isolated system. While the body is falling, its gravitational potential energy becomes kinetic energy. However' the total mechanical energy is conserved. Should the tube be filled with air, the system becomes an open one. In this case some of the mechanical energy would be transformed into-heat by friction with the air molecules.

The Principle of Conservation of Energy is one of the most important in Physics. It states that no energy creation or destruction ever occurs in any of nature's processes. There are only *energy transformations.* We can transform potential energy into kinetic, mechanical energy into thermal or electric energy, atomic or nuclear energy into heat and so on. But the total energy of the universe will always stay the same.

(b) A *preferential direction for natural processes.* Heat flows spontaneously from a body at a high temperature to another at a lower one. Should the reverse take place, that is, should heat be transferred spontaneously from the cooler to the warmer body, the total amount of energy **(heat) would still be conserved.** But this does not occur. There is, in nature, a preferred direction for the occurrence of such spontaneous processes. Lakes, for example, don't freeze spontaneously on a warm day by surrendering heat to their surroundings even though such a process would conform to the Principle of Conservation of Energy.

To take another example, consider a body which is falling freely through the air. Potential energy is transformed into kinetic. In addition, friction will cause both the air and the body to warm up. Potential energy is transformed into kinetic energy and heat. But the reverse process has never been observed; that would involve the thermal energy of the molecules of the air and of the body to be added to the kinetic energy of the body, and might even drive the body upwards! The Principle of Conservation of Energy would not exclude this (see figure 4).

There exists, then, a preferred direction for the occurrence of spontaneous natural processes. Any inversions of this direction can only occur when an external agent exerts an influence over the system considered.

We say that processes are *irreversible* when no reverse transformation can be made spontaneously by the system. As we shall see later, spontaneous processes lead systems into less organized states of energy.

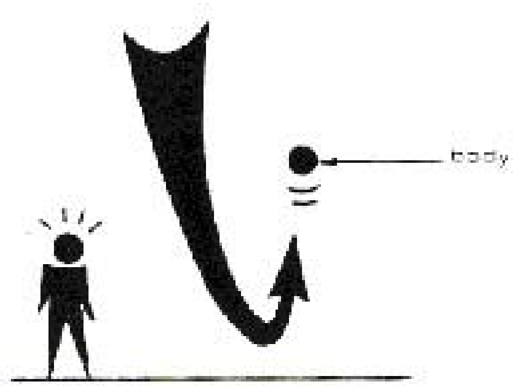

Figure 4. Transfer of thermal energy from the atmosphere to a falling body, driving the body upward, has never been observed.

3. Reversible and irreversible processes

Consider a system made up of a gas-filled cylinder fitted with a moving piston. Suppose that the gas will be led from the initial state i to a final state f, through intermediate and well defined pressure, volume and temperature states. If any small change in the environmental conditions (of temperature, volume or pressure) can take the system back from state *f* to state i, through the same intermediate states, the process is a *reversible* one.

However, if the pressure, volume and temperature of the gas cannot be perfectly defined for each of the intermediate states, or if a small alteration of the environmental conditions cannot take the system back from state *f* to state i through the same intermediate states, the process is *irreversible.*

Nature does not provide for rigidly reversible processes. But when a transformation from state i to state f is sufficiently slow, an almost reversible process takes place.

For example, should we throw one kilogram of sand all at once on to the piston of the cylinder (figure 5) the gas compression process would be irreversible. But, should we throw the same mass of sand on to the piston gram by gram and very slowly, the gas would undergo a reversible transformation between the states (figure 6). If the sand were slowly withdrawn, the gas would return from state f to state i through the same intermediate states.

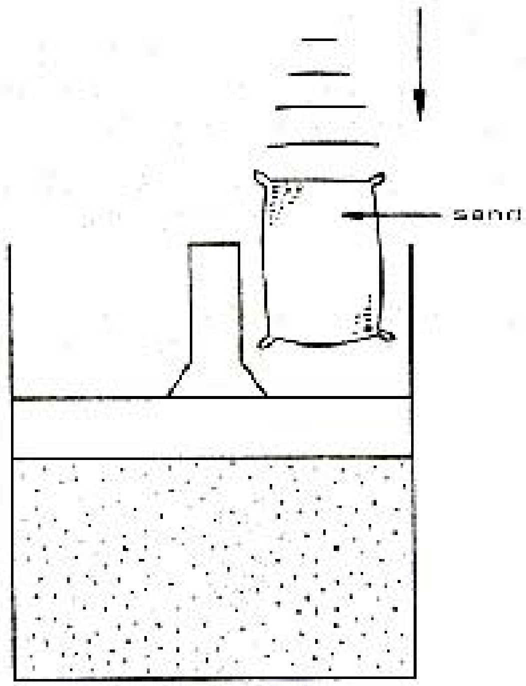

Figure 5. If 1 kg of sand is thrown all at once on to the piston, the gas compression is irreversible.

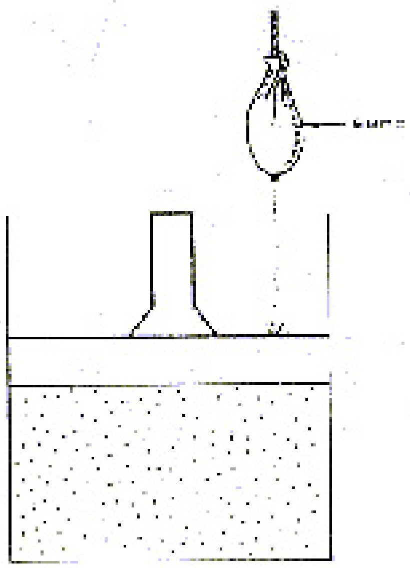

Figure 6. If 1 kg of sand is placed on the piston, grain by grain, the compression is reversible, provided that the sand is withdrawn equally slowly.

Consider a further instance. If the gas temperature is suddenly increased by putting the cylinder in contact with a reservoir of heat at a higher temperature, the transformation which occurs will be irreversible. But we may achieve the transformation through a nearly reversible process between the same states of temperature, pressure and volume. We must put the cylinder into contact with a series of several reservoirs at slightly different temperatures. Thus, if we wish to increase the gas temperature from Ti to *Tf,* where *Tf>Ti,* in a reversible way, we must provide several reservoirs with temperatures Ti + 6 T; T1 + 2 A T; T1 + 3 A T . . . etc., where AT corresponds to a small temperature increase.

At each stage we must allow sufficient time for the gas and the cylinder and the heat reservoir to reach thermal equilibrium; this process must continue until the gas reaches the desired temperature *Tf*

APPLYING THE MODEL TO THE SAMPLE OF THE TEXT

One lesson was thought necessary to cover the material quoted in the above sample and the planning of that lesson is detailed below.

I **Reading**

2. **Identification of basic objectives**

(a) *Task specification*

To define a physical system. Give examples.

To define the boundary and the surroundings of a system. Examples.

To distinguish between open and isolated systems. Examples.

To give examples of processes which, although not occurring spontaneously in nature, do not infringe the principle of conservation of energy.

To define reversible and irreversible processes.

(b) *Specification of operational objectives*

Q. Define a physical system. Give examples.

A. A physical system is any part of the universe which is either physically or mentally isolated for study. Examples: the Milky Way; the Earth/Sun system; a charged object in an electric field; a particle in motion; any similar response.

Q. Define 'boundary' and 'surroundings' of a system.

A. The boundary of a system is the surface that encircles it. Excluding the system itself, the remainder of the physical universe constitutes a system's surroundings.

Examples: Consider (a) a soft drink bottle as a system. The rest of the universe constitutes the surroundings. The outer surface of the bottle is the boundary of the system.

(b) gas contained in a cylinder and enclosed with a piston. The rest of the universe is the surroundings; the outer surface of the cylinder and piston is the (movable) boundary.

(c) any equivalent example.

Q. Define an open and an isolated system. Give examples.

A. A system is open when matter and/or energy can be exchanged with its environment. Examples: a soft drinks bottle after being opened; animals; plants; a pan during cooking. A system is isolated when matter and/or energy cannot be exchanged with its environment. Examples: a tightly closed thermos bottle; a body in free fall in an evacuated container; any equivalent answer.

Q. Give some examples of processes that would not infringe the principle of conservation of energy but which do not occur spontaneously.

A. A flow of heat from a body at a low temperature to one at.a higher temperature. The transformation of kinetic into gravitational potential energy.

Q. Define reversible and irreversible processes. Give examples.

A. A process is reversible if the system is able to revert from final state f to initial state i through the same intermediate states as in the transformation from i tof. When no sucil reversion is possible the system is irreversible. All spontaneous natural processes are irreversible: some non-spontaneous, extremely slow transformations are nearly reversible (or any equivalent answer).

3. Planning the revision of the pre-requisites

During this first lesson, the existence of the necessary pre-requisites must be assumed.

4. Planning activities related to the basic objectives

Such activities will include revision and discussion of points within the reading matter which the teacher deems relevant.

5. Planning the discussion of the reading

This discussion will consider examples of physical systems, the boundaries and the environment of a system, the difference between open and isolated systems (with examples), the conservation of energy, the existence of a preferred direction for the occurrence of natural phenomena, spontaneous processes, reversible and irreversible processes.

6. Determining supplementary objectives

(a) *Task specification*

To demonstrate that no rigidly isolated systems exist in nature.
To demonstrate that spontaneous processes occur in such a way as to direct the system towards the most probable energy states.

(b) *Specification of operational objectives* To demonstrate that no rigidly isolated systems exist in nature.

Examples: commonly used examples of isolated systems include thermos bottles, calorimeters and Newton's vacuum tube. A thermos bottle is a system that, over a certain period of time, conserves the temperature of a liquid at the level it was at when poured into the bottle; however, some measure of exchange with the surroundings occurs even over short time intervals. A calorimeter is a container which insulates a substance thermally from the environment in which it is located. However, since no perfect thermal insulators exist, some measure of heat interchange with the environment will occur. Newton's vacuum tube is a system used to study the fall of bodies in a vacuum. However, as a perfect vacuum cannot be produced, a certain amount of the mechanical energy of the falling body will be dissipated by friction with the air molecules in the tube.

An isolated system is an abstraction used to simplify matters when solving some problems. Rigidly isolated systems do not exist in nature. Or any similar answer.

Q. Demonstrate that spontaneous processes occur so as to direct the system towards the most probable states of energy.

A. The 'entropy' of a system is related to the probability that the system will be in a certain state of energy.

The most probable energy states, i.e. those with a high probability of occurrence, are those with the highest entropy. This can be verified through the defining equation for entropy S = kInW, where S is the entropy of a system in a certain state of energy, k is tile Boltzmann constant and W is the probability of occurrence of the state concerned. This equation links classical and statistical thermodynamics. According to the second law of thermodynamics, spontaneous processes take place in such a way as to increase the entropy of the universe, leading the system to the most probable state of energy. The increase of entropy of the universe can be interpreted statistically in terms of the probability of occurrence of energy states in a system.

7. Planning activities related to the supplementary objectives

The teacher shall perform such activities only in the event that there is sufficient time and if the proficiency level of the students is adequate. They might include:

A lecture showing that the systems offered as examples of isolated systems are not perfect since they interact with the environment even over the smallest time interval. An explanation of some of the concepts of statistical mechanics at any appropriately elementary level.

8. Planning for motivation

Motivation is assisted by presenting students with interesting phenomena or events in physics, without providing an explanation. So the teacher might show how energy is conserved in the spontaneous freezing of a lake on a summer day, or when a simple pendulum starts to swing, impelled by the moving air molecules. Then he might ask the students why such events don't occur since the Principle of Conservation of Energy is observed.

9. Planning the mode of assessment

The teacher will encourage student participation in discussion. Then, he will be able to assess whether or not the basic objectives were generally attained. And during his treatment of the supplementary objectives, he will be able to verify whether or not these objectives were achieved.

Should it be possible to obtain written answers from the students, or from groups, and to correct these, the teacher will be better able to assess the students' achievement.