CHAPTER 3: TEACHING SCIENCE, MATHEMATICS, TECHNICAL AND VOCATIONAL SUBJECTS IN AN INTERRELATED WAY

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Introduction

In many schools the curriculum is based on a timetable of separate subjects serviced by specialist teachers who work in isolation from teachers in other subject areas. Also, subjects are offered as an academic discipline with little or no reference to their practical value. In these situations the teaching of science and technology-based subjects is largely confined to the classroom and the importance of doing, making and organising is often neglected.

In order to break down the rigid lines of demarcation between subject disciplines the interrelationship between subjects must be recognised and exploited so that science and technology education is treated in a comprehensive way. The need to inter-relate science, mathematics, technical and vocational curricula is clearly seen by an examination of technological developments in the world of work. For example, the scientific research laboratory in chemical-based industries uses modern technology as a basis for measurement and the interrelationship between mathematics, physics, biology and chemistry is fundamental and undeniably strong, especially in respect of one simple mathematical concept, namely ratio and proportion.

It seems natural, therefore, to relate science,mathematics, technical and vocational subjects so that rigid boundaries are crossed in a smooth and effective way. Such interrelation will provide an education with interest and purpose, and assist the process of incorporating new technologies into teaching programmes. In order to reap the maximum benefit from an inter-related approach to the teaching of science and technology subjects, two essential requirements must be met - the cooperation of teachers and the provision of comprehensive teaching modules.

An interrelated approach to the teaching of science and technology subjects is likely to stimulate a greater motivation to study. Many pupils find that the isolated nature of school curriculum subjects - with little reference to experience related to the world of work - is totally irrelevant to their perceived needs. Dissatisfaction with traditional academic curricula may be one of the underlying causes of behavioural problems that arise in the final years of formal schooling.

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It must be recognised that any change from traditional curricula to a more interrelated approach is likely to be opposed by some teachers who may have serious misgivings about such curriculum reforms. However, if teachers are fully involved in every stage of change they are likely to modify their attitudes and agree that the successful development and implementation of interrelated curricula must depend on a new teaching approach - with a greater emphasis on gudiance for teachers. The preparation of curriculum materials, guidelines on implemention, management and assessment are also activities that require the participation of teachers and their whole-hearted support. Other areas of co-operation between teachers and education authorities are concerned with pre-service and in-service training, their implementation of interrelated curricula, and the provision of resources including buildings and equipment.

The interrelation of science, mathematics, technical and vocational curricula is likely to follow two separate, but related development paths:

(a) The interrelation of existing curricula following identification of related topics.

(b) The design of teaching modules covering topics commonly used in all science and technology subjects.

Resource constraints and a need to proceed in a step-by-step manner may favour the adoption of (a). However, in the long-term the development of interrelated curricula will lead to the production of special modules as described in (b). One topic, of essential use in all science and technology subjects, is measurement. Even at pre-school level measurement is important in respect of counting, classification and recognition. In later stages of education, measurement is the all-pervading topic in every aspect of science and technology education. The purpose of this paper is to develop a teaching module on measurement, together with guidelines on ways to present it as an interrelated topic with a view to helping communication in science, mathematics and technology.

A further purpose of this paper is to provide a basis for discussion amongst groups of teachers, educationalists and parents so as to help the learner to understand the reason for studying a variety of school subjects. It is hoped that the ideas in this paper will provide some enrichment in the curriculum thus opening new lines of communication between the teachers themselves, provide cross-fertilisation amongst subjects and thus increasing communication between teachers and students as well as between students. In addition, the links between the students and the society in which they are living and in which they are hoping to make a contribution will be further strengthened.

Measurement in Science and Technology

In all science and technology subjects the measurement of physical properties is an essential objective, or a necessary component of an objective.

Physics and Chemistry are taught as a set of principles and practical phenomena, the latter being quantified by fundamental measures (count, time, length and mass) or as derivations, for example:

- specific heat from volume (length), mass and temperature
- modulus of elasticity from mass and length
- melting point directly from temperature
- co-efficient of thermal expansion (length), area or volume) all in terms of length and time
- electric charge from mass and time in a chemical cell
- molecular weight from atomic weight and a count of atoms
- density from mass and volume (length)

Biology takes account of the fundamental cell structure of animal and human forms, the macro-components of which have identifiable properties and specific structures which relate to particular species. The following examples illustrate some ways in which measurement occurs within biology:

- counting is used to establish and verify laws of genetics
- time is used to measure (with counting) pulse rate and heart beats
- cells are identified by colour and shape as determined by the configuration of lengths and angles
- cell multiplication is determined by counting and measured against temperature
- count of macro-components, eg. number of ribs, vertebrae, etc.

Technical Education supports the fundamental industrial processes, namely design and manufacture. Measurement takes place at all stages varying from the use of elementary instruments to automatic, continuous monitoring devices. Examples of measurement are as follows:

- counting and classification
- shape, angle and size are measured with geometrical instruments
- smoothness is measured by the abrasiveness of filing and sanding devices
- automated machine tools can be programmed to produce a finished product having predetermined measures
- temperature is measured continuously and automatically regulated in order to maintain a constant temperature in the heat treatment process
- hardness of metals is measured on a variety of scales

Mathematical education is concerned with the training of clerical, operative, retail and wholesale distributive trades. Formal education is usually available eg. in the office skills. Examples of measurement are:

- shorthand/typewriting speed; teaching tabulations to typists
- money calculations as taught to clerks, cashiers, hotel receptionists, etc.
- reading electricity supply meters
- making clothes and other items in small businesses/cottage industries
- weighing of raw materials by process workers
- measuring of customers in shoe and clothes shops to obtain appropriate sizes
- measurement involved in buying some improvement materials, e.g. timber, screws and various fittings

Teaching Measurement - An Interrelated Approach

In order to present the topic of measurement in an interrelated way it is necessary to establish a number of objectives and identify supporting strategies.

To assemble a team of specialists from a teaching establishment who are sufficiently interested and motivated to co-operate in the use of interrelated curricula

Strategy: Identification of a co-ordinator who has specialist knowledge and teaching experience in one or more of the related areas. There must be a full acceptance of the new subject INTERRELATED STUDIES within the establishment. This would not mean that specialist subjects would no longer exist in the timetable any more than one would expect, for example, that mathematics, science, English and other topics would not exist for students studying A-level general studies in the United Kingdom.

To motivate the students to learn.

Strategy: Use of colourful, attractive and well-prepared materials which relate to the real-life experiences of students. The co-operation of local commercial and industrial organisations must be sought - it is the experience of the author that a considerable amount of support is usually available.

The prepared material should take into account teaching strategies, programme planning, laboratory management and assessment. Teachers need help in these strategies right at the start so that they can develop new curricula.

To ensure that teachers are sufficiently prepared to cope with an interrelated approach, by means of an available teacher/pupil module and separate pupil modules.

Strategy: Preparation of separate teacher and student modules. The teacher module, while containing the student's material will be much more comprehensive in respect of background information, and the use and variation of this material will be at the discretion of the teacher. Solutions, hints, etc., for student exercises will also be provided. The format of the teacher module will clearly show the separation of teacher and pupil material. The teacher/user must understand that the content of the module will require regular updating by the teacher.

To draw on the experiences and particular interests of students.

Strategy: Teachers and students will need to bring together skills, experiences, knowledge, understanding, imagination and judgement in order to solve a problem. The teaching of these will be a difficult task but it is hoped that students will learn through experience and practice under supervision by the teacher.

Students' experiences, though sometimes not first-hand, are always relevant, e.g., space travel through television broadcasts. It is important to give guidance on the collation and recording of experiences and interest material. An example is that of newspapers, being particularly useful as they regularly report on developments in commerce, industry and technology.

To ensure that the treatment of important phenomena is at a level of explanation suited to the students.

Strategy: Demonstrations will help to show the results of theoretically derived relationships. Actual experiments carried out by the students should be encouraged for them to understand the explanations of the phenomena under investigation. Where results are to be expressed graphically, a linear graph should be used and, where appropriate, a logscaled graph (detailed explanation of logarithms may be left until a later stage).

To consolidate learning processes by suitable student exercises.

Strategy: The exercises should be requested as the response to key questions and in simplest form this could imply a descriptive essay. At the other end of the scale problems requiring numerically calculated answers should be applicable to real-life situations, whenever possible. Practical and investigative assignments would need to be carefully structured and checked for continuity with particular attention paid to the time for completion by the average student. Where there are weaknesses in pedagogic, arithmetical and algebraic processes, suitable practice exercises (with self-checking facilities if possible) must be available. Using these strategies teachers should guide students towards independence in their learning as a preparation for the world of work.

To produce modules which are sufficiently flexible for a variety of teaching methods to be employed.

Strategy: There must be regular discussions between members of the teaching team to promote a greater use of audio-visual aids. If such aids are in short supply, e.g. micro-computers, it is acceptable to have a single piece of apparatus for use with a class. As an extreme example of the non-availability of apparatus for student use, the teaching of atomic energy generation has to depend entirely on slides, films, models and diagrams.

Sample Modules on Measurement

In order to demonstrate how the teaching of measurement in an interrelated way can be carried out according to the above strategies, extracts from sample modules for teachers and students have been prepared and are being evaluated. It is stressed that these modules are in outline form and require more refinement, proper testing and evaluation. (The topic of measurement has been applied to three vastly differing fields of general worldwide interest - the motor car, the pharmaceutical industry and the construction industry.

Students and teachers in countries at all stages of development should find the subject areas of cars, pharmaceuticals and buildings interesting and relevant. Block diagrams of the modules on these topics so far prepared show the many ways in which measurement occurs in science, mathematics, technical and vocational subjects. (See Appendix A.)

In addition, slides with commentaries for use by teachers and students, illustrating the all-pervading nature and the importance of the topic of measurement have been prepared. Some of these are currently being evaluated and it is hoped that after further development work, a comprehensive set of material for teachers and students will be available to Commonwealth countries. (An extract from the tape-slide programme is shown in Appendix B.)

Preparation of Interrelated Modules

The following guidelines on the preparation of interrelated modules are based on experience gained in the development of the modules on measurement. It must be emphasised that there is no unique 'modus operandi' in this process and teachers will use the most appropriate method, depending on the resources available and the conditions prevailing in their own countries.

Preliminary discussion should be held amongst teachers regarding the need for an interrelated approach in teaching within a certain topic area. This should identify a topic which lends itself to an interrelated treatment in the form of a module(s). Once a decision to produce a module(s) is made the following steps to develop it may be taken. It is essential that clear objectives, based on sound educational principles, are adhered to in the development of such a module.

Guidelines:

- Assemble the 'teaching team'
- Outline the plan of action using a flow/schematic diagram, decide the title (which may be revised), and set the time schedules for module construction

- Define the target student group (age, range, pre-requisite knowledge, type of educational establishment)

- Formulate general and specific objectives

- Produce motivational material to show teachers and students the relevance and interrelationships of the topic

Note: this could be achieved through illustrations, purposeful in style and related to practical settings. Suitable material could be obtained by:

Contracting commercial/industrial establishments to gather advertising, audio/visual materials

Seeking the co-operation of parents of students to obtain support material/equipment

Encouraging teachers and students to explore the local environment for pictures, specimens (biological, physical, chemical, geological and ecological); and locally available material in order to make low-cost equipment to support the practical content of the module

- Allocate the following to the members of the team as individual or group assignments:

  preparing motivational materials in the form of texts, charts and tables

  pictures (in colour or black and white)

  overhead transparencies

  slides/audio tapes

  films/video tapes

  teacher modules in text form (with diagrams, illustrations)

  student modules in text form (with diagrams, illustrations)

- Assemble selected draft material, ensuring that the key points in the modules are suitably highlighted

- Discuss the final draft within the team and consult external bodies/persons. Modify as necessary

- Formulate procedures for testing and evaluation in a 'Pilot Study'. Agree procedures with students/ teachers/parents/education authorities and any other parties whose involvement is essential for the success of this approach

Note: It would be highly desirable to supply at least one original set with the multiple copies, so that participating teachers and students could see the module in its original form

- Test the final version before making it available for general use

- Explore the possibilities of getting the module published so that a larger body of students and teachers could use it

Implementation of the Programme

Provision of suitable accommodation should be given high priority in the initial discussions by the team. It is possible that a room suitably equipped to teach interrelated modules may not be available for some time. However, it must be stressed that much can be achieved with few resources given the right enthusiasm and careful planning. Suitable in-service training programmes for teachers should be provided to make each member more familiar with disciplines other than their own. Allocation of time for in-service training and extra-curricular activities may have to be made available within the normal working day.

The availability of resources is bound to vary and it is quite conceivable that extra funds may not be immediately available to purchase equipment. The teacher should study the feasibility of using available resources in the most efficient way - this would certainly require co-operation and assistance from teachers outside the team.

Assessment should be discussed to formulate an appropriate scheme although this may not be possible at the commencement of the programme. After some experience of teaching the module as a team, methods of assessment should be suggested, tried and modified in the light of feedback.

Role of Educational Technology

The use of educational technology has been stressed throughout this paper. Such methods should be adopted whenever possible by teachers everywhere so that their students find some excitement and interest in the presentation of the modules. Many teachers, particularly from countries in Africa and Asia, would argue that some of these facilities are not available to them. Such problems must be recognised but it is suggested that education authorities would be more willing to provide educational technology equipment if they are convinced that its use is essential and beneficial to new and innovative teaching methods.

Distance Learning Methods

It would be a great pity if good and interesting modules were developed by an enthusiastic team of teachers and were not made available to a large body of teachers and students in other parts of the continent as well as other countries in the Commonwealth. One way to achieve this dissemination would be through well produced and attractive teacher/student modules published at a subsidised cost. Another method would be to exploit 'distance teaching' strategies which are finding great prominence in many parts of the world. These strategies would have to be employed on a large scale for the pre- and in-service training of teachers.

Modules - Early Experiences

A number of topics have been evolved and tested with the help of students and staff at Burleigh College, a British comprehensive Upper School with students for the age range 14-18.

One of the projects involved 15 year old Engineering Science students who were asked to design and make a device capable of counting 50 tablets. This project involved students producing finished articles using mainly "junk" materials at very little cost, and illustrated that projects associated with an interrelated approach do not always require expensive equipment and materials in order to be successful.

As a result of preliminary work on the interrelated teaching of a number of topics the following observations can be made:

- We found that an interchange of ideas between teachers brought about mutual understanding of how various curriculum areas operate in terms of classroom management, teaching techniques and syllabus content. It enriched the knowledge, and broadened the experiences, of the teachers involved.

- We noticed that with a team of teachers working together on a topic, students obtained a variety of ideas and opinions from a number of people with different skills and interests. This promoted much discussion.

- The enthusiasm shown by the staff involved in the project produced enthusiasm amongst the students.

- We found that, in order to produce modules which were both stimulating and well structured, we needed: time to meet, discuss and thoroughly plan; time and modest resources to produce/obtain well presented, appealing materials for students; and time to evaluate the work, paying special attention to comments/suggestions made by students.

- Modules/projects currently being tested have generated much interest from teachers not involved in their planning.

Measurement in the Construction Industry

The assistance of the experimenter was requested by a Building Department Tutor in the teaching of mathematics as relevant to Craft Bricklayers under a Youth Training Scheme. After discussions it was agreed that an 'interrelated' approach for teaching these students be adopted and a module was prepared.

Students: 18 in class; 16-18 years of age
Duration: 8 hours
Venue: Wirral Metropolitan College, Merseyside, England
Aims of Module:

(a) Study of measurement through calculation, and discussion using relevant quantities in practical situations.

(b) Establish an appreciation of the interrelationships which exist between mathematics, science and technology involved in the subject.

(c) Encourage a sensible approach to calculations in respect of rough estimation, approximation, interpretation of results and the use of calculating aids.

The great interest generated amongst students and staff in the above experiment resulted in the experimenter being invited to show the programme of slides on 'measurement' to members of the Numeracy Sub-Committee of the North West Regional Advisory Council for Further Education. The latter's interest has also resulted in requests to try out the module of study with another similar group.

Conclusion

A case has been presented in this paper to teach science, mathematics, technical and vocational subjects in an interrelated manner to overcome the deficiencies and gaps in the way these subjects are currently taught. Students will find relevance and meaning in topics taught this way, in addition to the enjoyment and interest that will be generated. The salient features of an interrelated approach to the teaching of mathematics, science and technology through specially designed modules are summarised on the next page:

(a) Measurement is identified as an all-pervading topic in science, mathematics, technical and vocational subjects and as such is an ideal topic for development as an interrelated module.

(b) Appropriate teaching strategies, based on sound educational principles are developed as an essential part of an interrelated modular programme. The terms of reference and suggestions for the implementation of such a programme are proposed.

(c) Team teaching is advocated. This has a most important role to play in the successful operation of a programme based on an interrelated approach.

(d) Examples are provided of motivational material for use by teachers and students using educational technology to amplify some of the strategies highlighting the links between subject groupings.

(e) Formats for teacher and student modules are suggested. Hints and guidelines for teachers and students have been provided.

(f) In-service training is essential for the success of innovative curricula. Urgent steps will have to be taken to enable teachers to communicate with each other in order to become conversant with the new ideas.

(g) Distance learning methods would be useful in implementing the programme for in-service training on a large scale.

(h) Guidelines for constructing further modules are suggested based upon the experiences in producing and testing the modules under development.

Acknowledgements

The paper is concerned with an innovative method of teaching which requires much dedication and team effort on the part of those who believe in the pursuance of such an idea. I am indebted to two of my current research students, Mr. Stanley Turner and Mr. Rodney Bond, who are practising teachers in a college of further education and a comprehensive school respectively. Both of them have taken up my original idea with great enthusiasm and have been developing and trying material for teaching science, mathematics, technical and vocational subjects in an interrelated way. These trials have naturally involved students at school, at technical/vocational college level, as well as teachers who teach them. I wish to express my gratitude to these students and teachers who have

participated in the 'pilot studies', and also to the education authorities, parents and people from industry without whose help the experiment would have had no chance of success.

Note: The diagrams that follow have been prepared by the experimenter and his assistants.

MEASUREMENT AND THE MOTOR CAR

APPENDIX A

Measurement is concerned with: Speed, Distance, Time, Power, Rotation, Capacity, Temperature, Current, Voltage, Pressure, Noise, Pollution, etc

CARBURATION

Measurement of Combustion
- Air/Fuel Ratio
- Compression
- Engine Size
- Oil Pressure

ELECTRICAL SYSTEM

Measurement of Current
- Voltage
- Electrical Power
- Electrical Rating
- Charge of Battery

DESIGN OF SHAPE

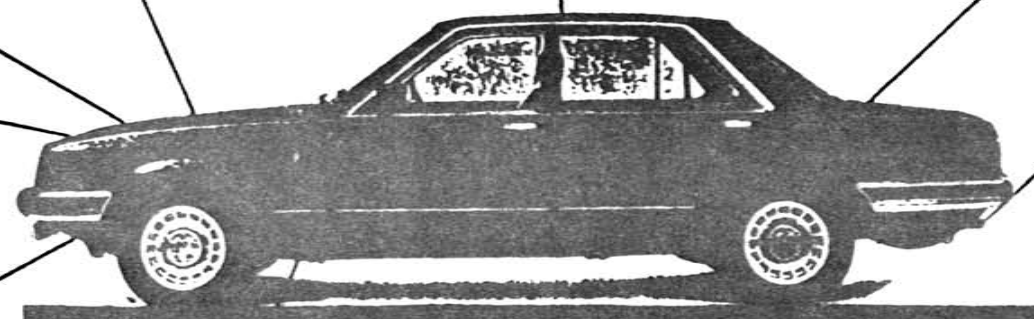
Measurement of Visibility
- Weight of Car
- Properties of Materials Used
- Corrosion
- Corrosion Prevention
- Drag Coefficient

FUEL

Measurement of Volume (Fuel in Fuel Tank)
- Fuel Consumption
- Economical Driving ('In Town' or 'On A Run')
- Octane Rating of Fuel
- Petroleum Production
- Fuel Cost

OILS AND FLUIDS

Measurement of Properties
- Viscosity



THE EXHAUST SYSTEM

Measurement of Noise
- Content of Exhaust Gases
- Pollution

COOLING SYSTEM

Measurement of Temperature
- Humidity (Heating System)

Thermostatic Control

Antifreeze

ROAD SURFACES

Measurement of Safety
- Stopping Distances
- The Effects on Suspension

GEARBOX

Measurement of Gear Ratios

TYRES

The Various Types

Measurement of Tyre Size
- Tyre Pressure
- Tread Depth

ACCESSORIES

Tow Rope (Strength)
Jack - Screw
- Hydraulic

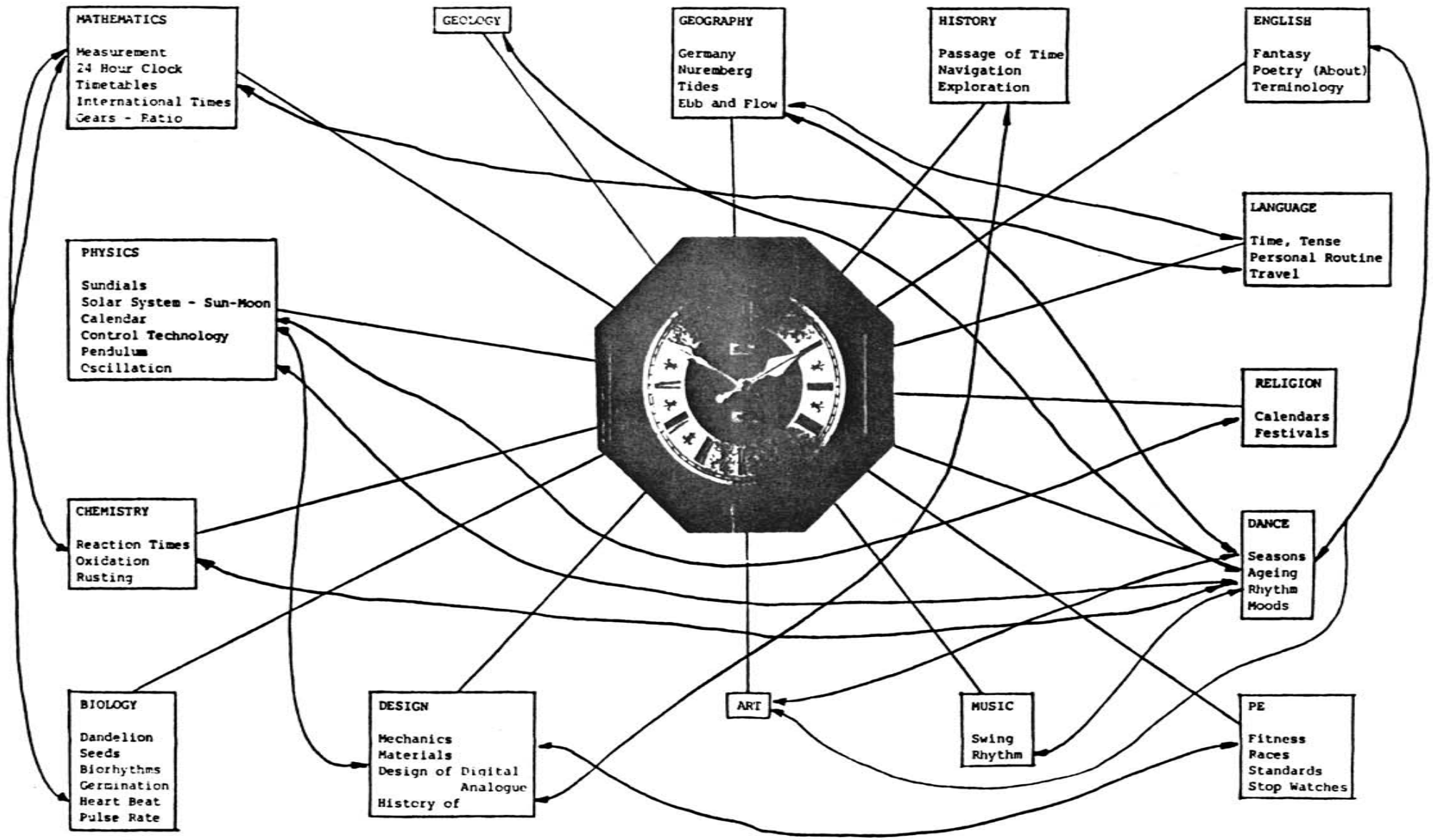
Fire Extinguisher
Battery Charger
First Aid Kit
Spanners

Measurement of Running Costs For
- Petrol
- Diesel
- Electric
- Solar Powered Vehicles

INTERRELATIONS CAN ALSO BE FOUND BETWEEN ELEMENTS WITHIN DIFFERENT RECTANGLES

CAMET

INTERRELATED STUDIES - BRAINSTORMING SESSION ON CLOCKS



MEASUREMENT IN THE CONSTRUCTION INDUSTRY

INTERRELATED STUDIES

COATINGS

Internal, external
Anti-pollutants
Structural protection
Surface protection
Membrane waterproofing
High performance coatings
Appearance

MATERIALS

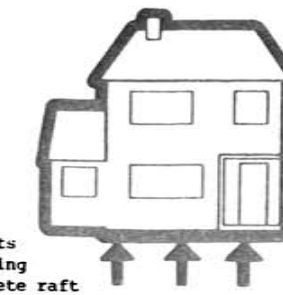
Water
Cement, aggregates
Steel, wood, glass
Polythene sheeting
Sundry fittings
Tools and measuring equipment
Transportation
Site offices
Amenity buildings

WALLS

Weight on foundations
Bricks, blocks
Cavity fillings
U-values
Sound insulation
Protection
Finishes

PLANNING

General outline
Selection of site
Local Authority constraints
Costs: construction, running, maintenance
Detailed plans
British Standards
Tenders
Contractual agreements

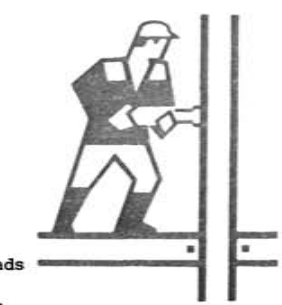


FOUNDATIONS

Ground survey
Site clearance
Site preparation
Biological treatments
Excavation and filling
Protection of concrete raft
Removal of earth

ROOFS

Effect on foundations
Thermal insulation: U-values
Skylights
Material
Flat or angled



STRUCTURES

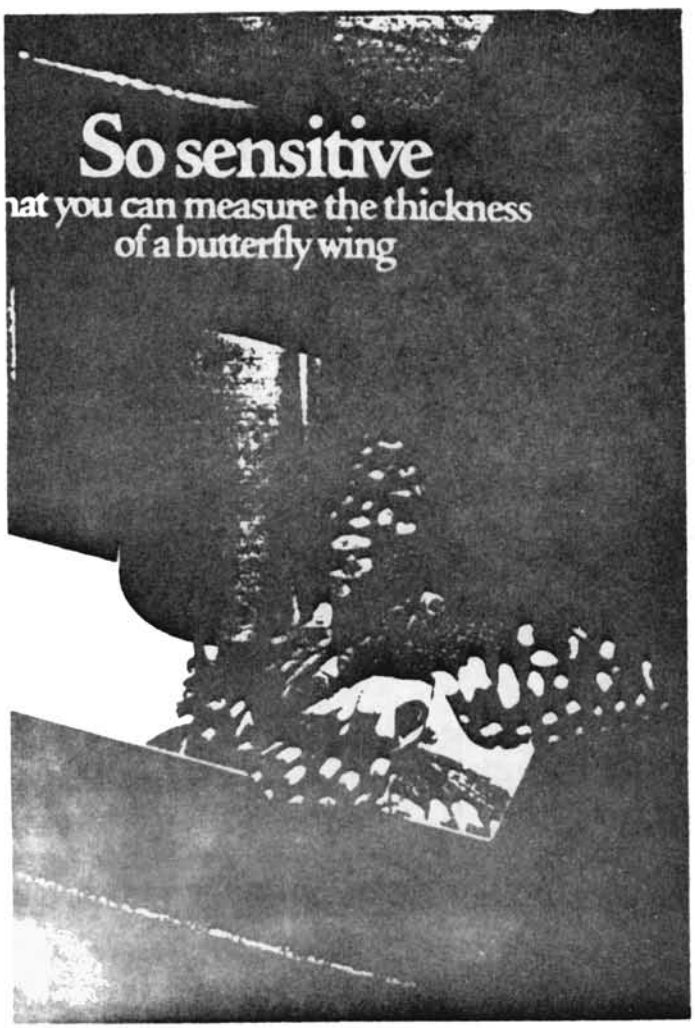
External loads
Floor loads
Calculations
Prediction of performance
Stability: extreme climatic variations
Steel, concrete

SERVICES

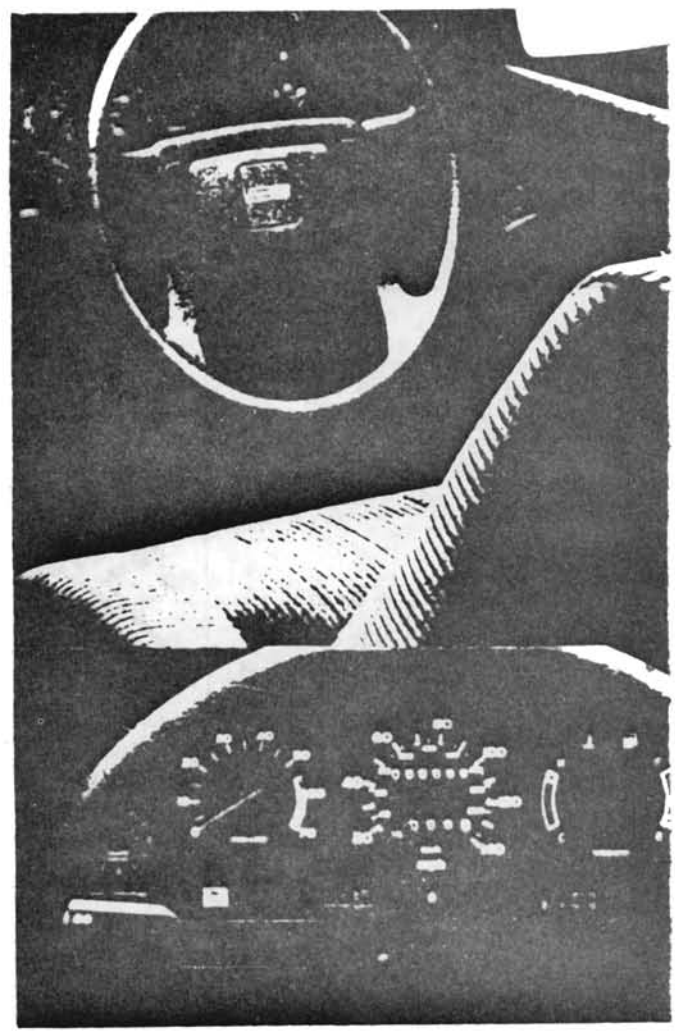
Initial access roads
Water
Electricity
Gas
Ventilation
Waste disposal
Permanent access roads

APPENDIX B

An Extract from a Tape/Slide Programme of 48 slides based on "Measurement" to illustrate INTERRELATED STUDIES



Slide 10*



Slide 29

Commentary for Slides 10 and 11

The wing is clamped so gently that the butterfly flies away, leaving a record of its wing thickness. Technology has been involved: the biologist and the butterfly are pleased.

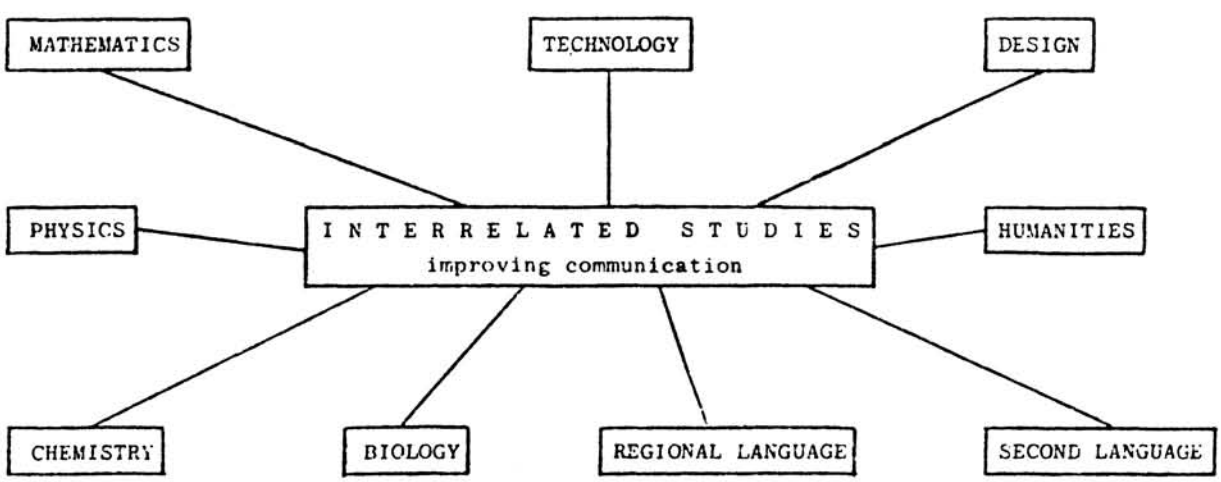
We combine basic measures to form one new time and distance combination to give speed. Each car has a speedometer and also instruments which measure for example temperature, volume of petrol, the charging state of the battery and the rotational speed of the engine in revolutions per minute...

*Slide 11 not shown

Slide 47

Every industry requires teamwork to produce the finished product. If they wish to achieve harmonious, efficient production then the parts of any industry must come together as naturally as nature brings together the segments of an orange.

Slide 48



Within schools throughout the world, to teach mathematics, science and technology in separated isolation may prove to be a worthless, meaningless exercise for many. If we can prove to our students that what we are asking of them is relevant to their existing and future experiences then we may generate both enthusiasm and interest. By relating our work in schools to actual everyday things we cannot treat subjects in total isolation. The products of today's society requires a marriage of science, mathematics and technology. For many students within schools an inter-related approach may be the way forward - the way in which their curriculum takes on a new exciting look. If, using this approach, we can arouse curiosity and generate interest then we will have achieved a great success in communicating through INTERRELATED STUDIES.